National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

The 9x7 Wind Tunnel Sonic Boom Measurements and Computational-Experimental Comparisons

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Objective and Challenges
Supersonic Cruise Efficiency – Airframe

Objective:

- To improve computational and experimental capabilities for highly-efficient low-boom supersonic vehicles

Challenges:

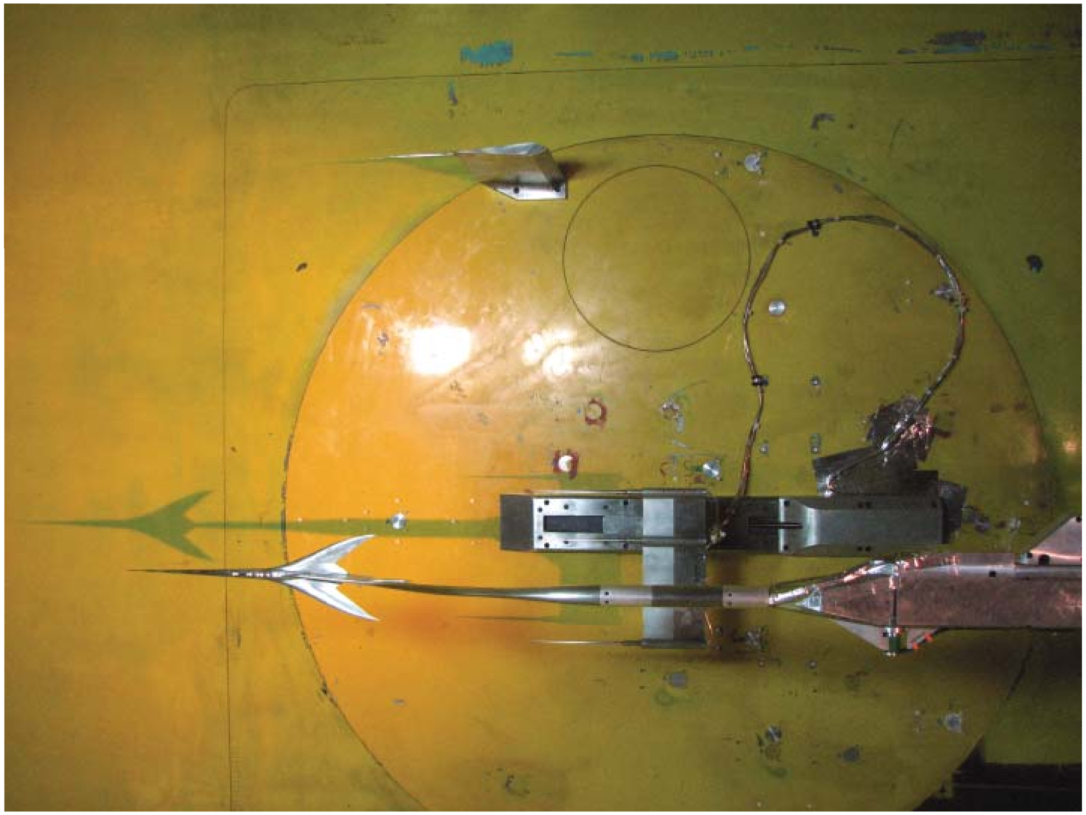
- To develop robust CFD-based methods for rapid design and analysis of supersonic cruise aircraft that are highly efficient and have a low sonic boom
- To develop improved wind tunnel testing methods and hardware that are capable of measuring sonic boom pressure signature for vehicles with low overpressures

Outline

- Summarize NASA sonic boom instrumentation in 9x7 WT
- Introduce new approach to sonic boom testing
  - Reflection factor 1.0 rail design
  - Spatial averaging techniques and best practices
- Present new CFD unstructured grid generation method for accurate sonic boom analyses
  - Mach cone aligned prism method
- Present experimental results and CFD comparisons
  - Lockheed Martin N+2 blade sting
  - Lockheed Martin N+2 conventional sting
  - Boeing AS2 body of revolution
- 9x7 Parametric Test Plans

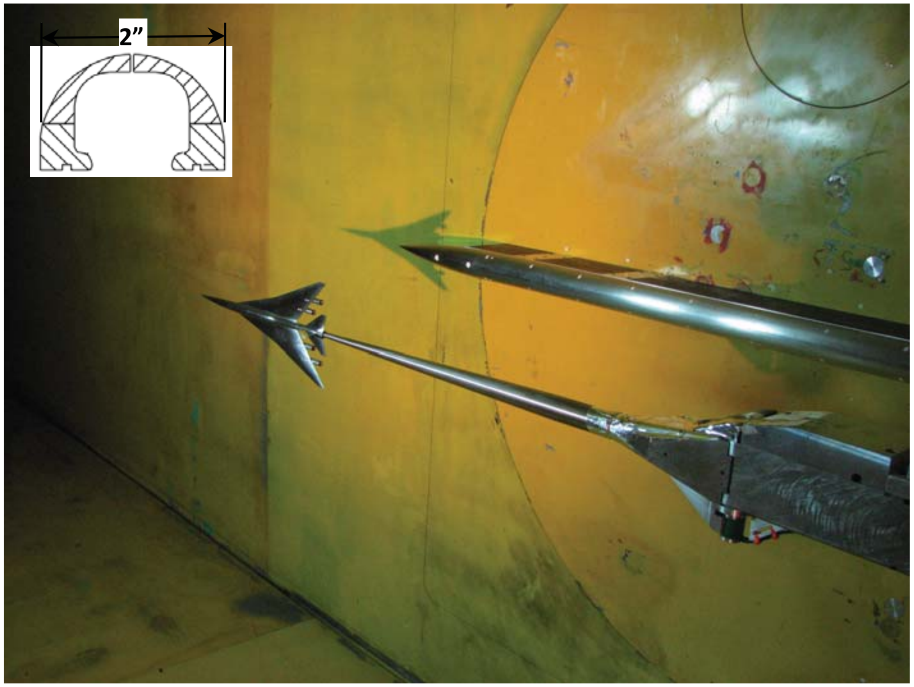
Conventional Probes, 2008

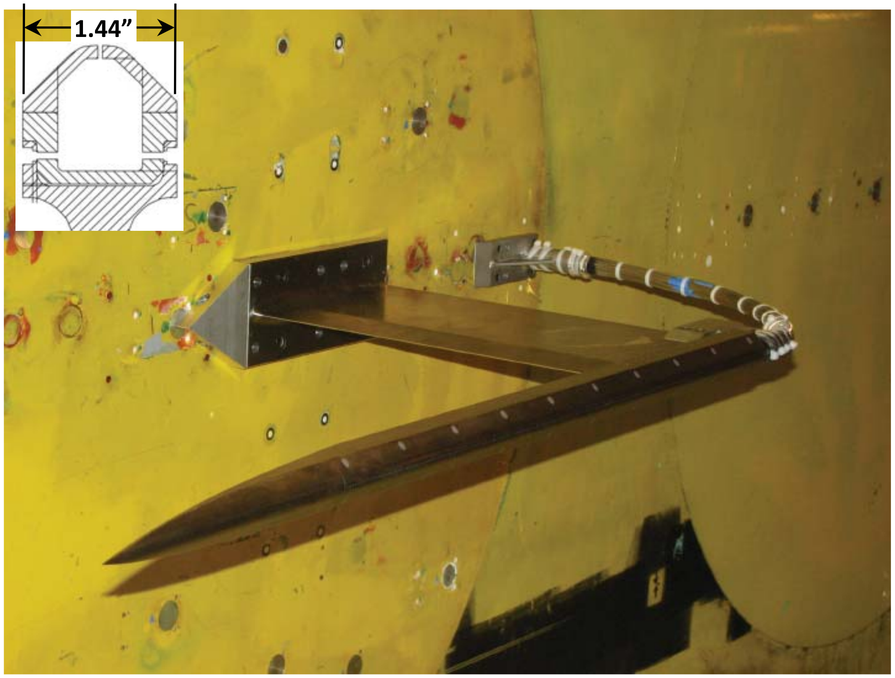
Ames probes, orifices 10 in. from wall



Gulfstream probes, orifices 10.5 in. from wall, mounted on traverse for optimal positioning

Pressure rails, 2008

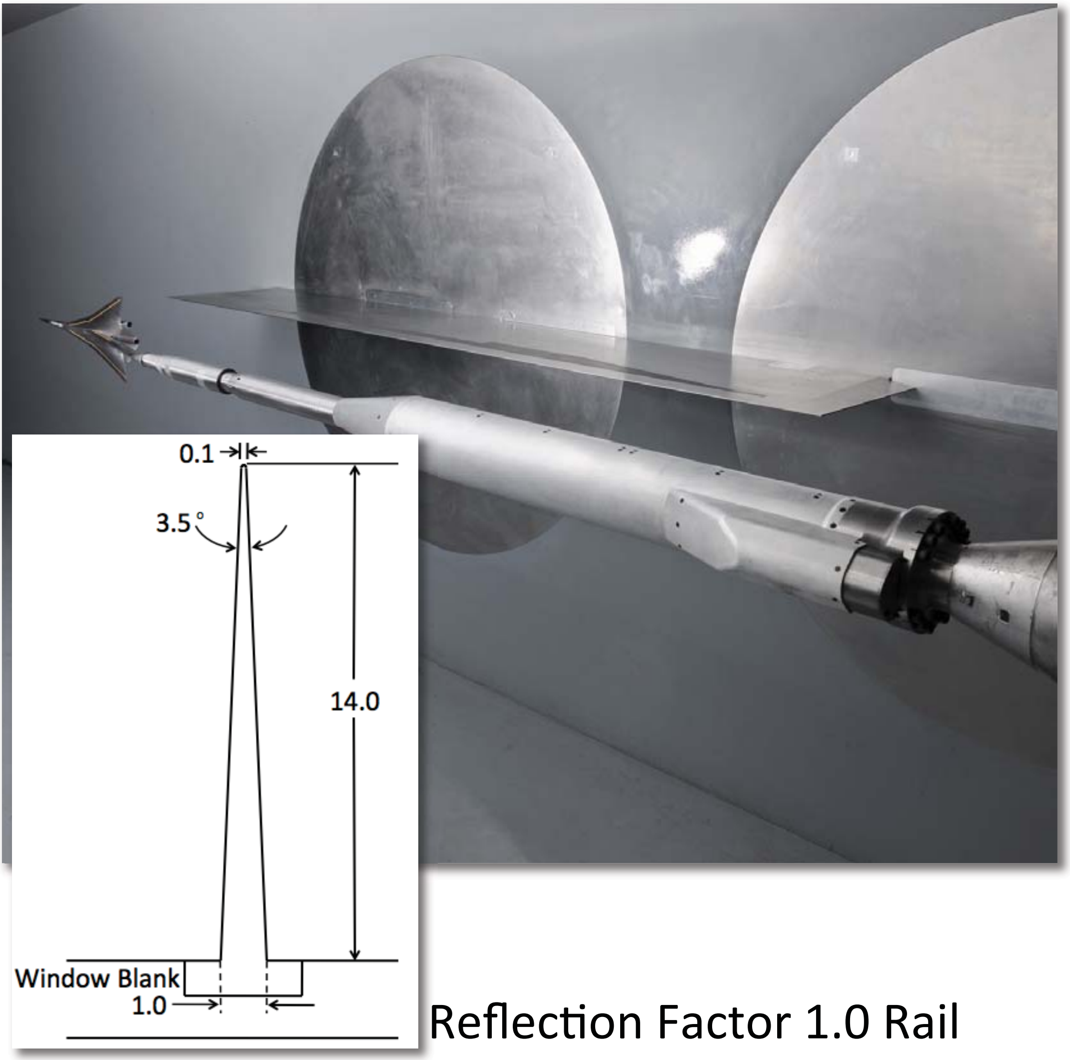




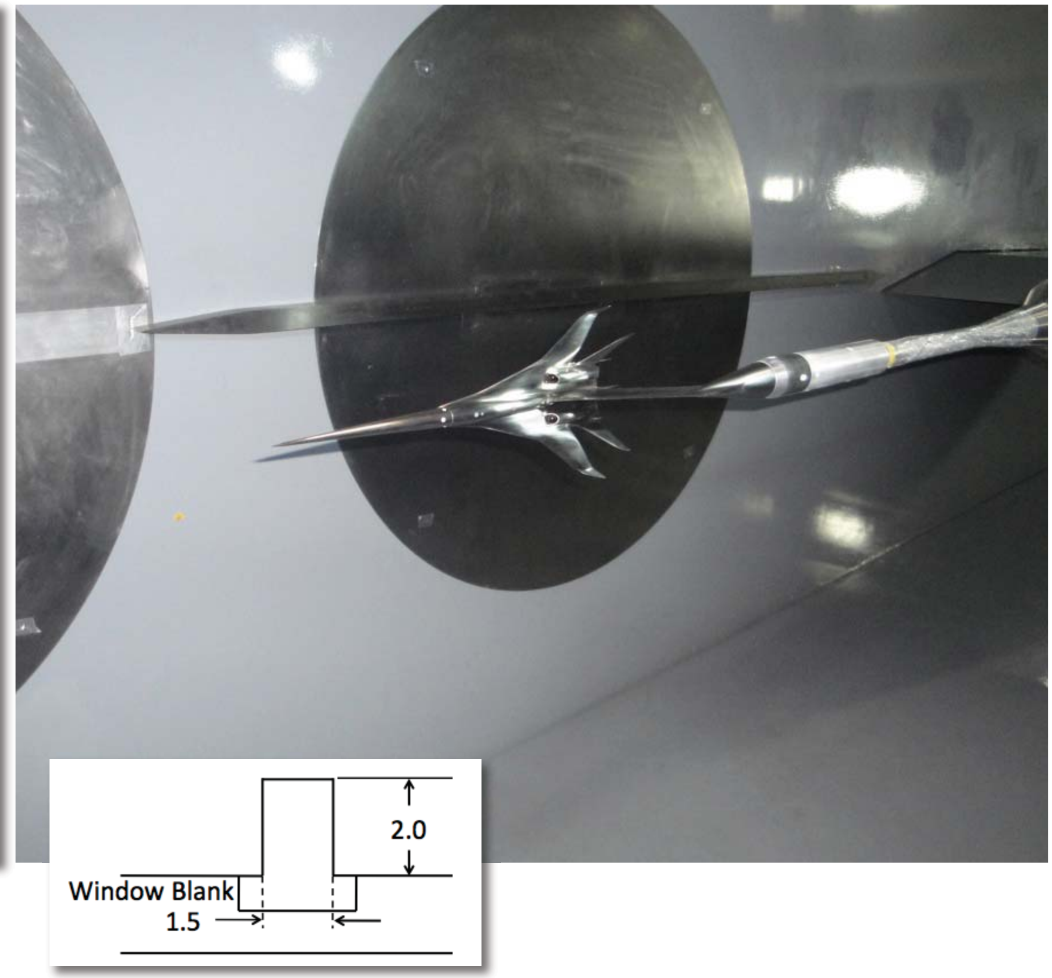
Wall Rail with 4 in. standoff
Rounded 1.0 in. radius tip
5.25 in. from wall (1.25 in. w/o standoff)
60 in. long
385 orifices along 48 in. of rail

Mast Rail
Flat with with beveled edges tip
18 in. from wall
36 in. long
160 orifices along 20 in. of rail

Pressure rails, 2010-2011



Reflection Factor 1.0 Rail
Rounded 0.05 in. radius tip
14 in. from wall
90 in. long
420 orifices along 66 in. of rail



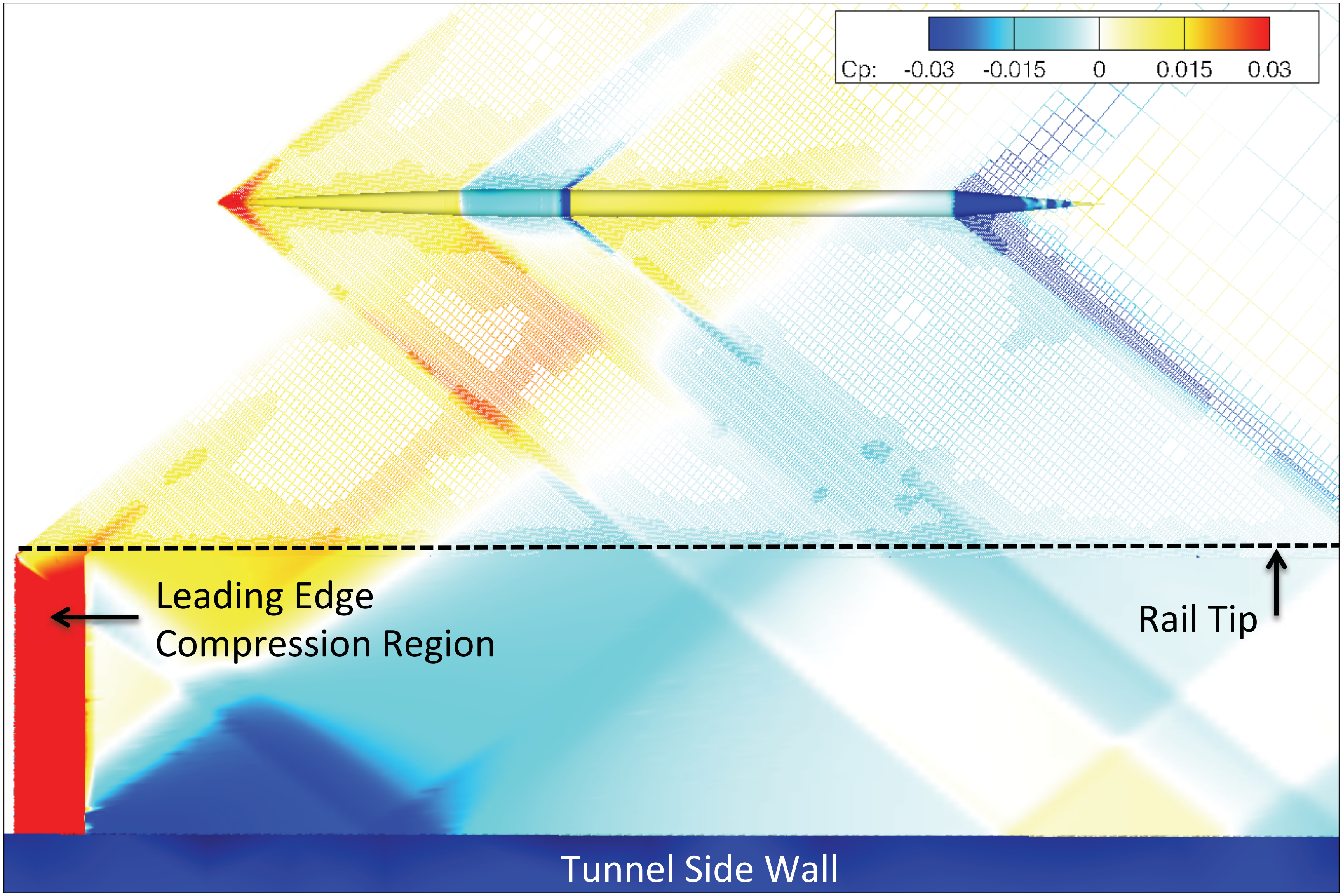
Conventional Rail
Flat tip
2 in. from wall
96 in. long
458 orifices along 72 in. of rail

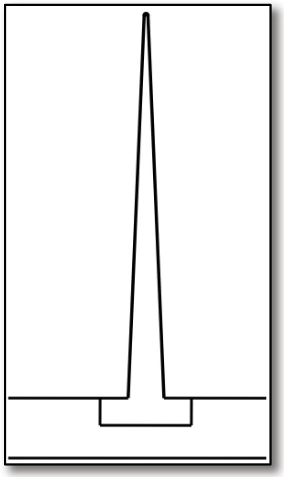
Instrumentation Assessments

	Single Orifice Probe	Wall Rail 2008	Mast Rail 2008	RF 1.0 rail 2010, 2011	2" Wall Rail 2011
Consistant Reflection Factor	Good	Poor	Fair	Good	Poor
Productivity	Poor	Good	Good	Good	Good
Accuracy	Fair	Poor	Poor	Good	Poor
Model Size Flexibility	Good	Poor	Good	Good	Poor
Forward Shape/ Bow Shock	Good	Poor	Fair	Good	Fair
Boundary Layer Influence	Good	Poor	Good	Good	Poor
Fabrication Costs	Good	Fair	Fair	Fair	Fair

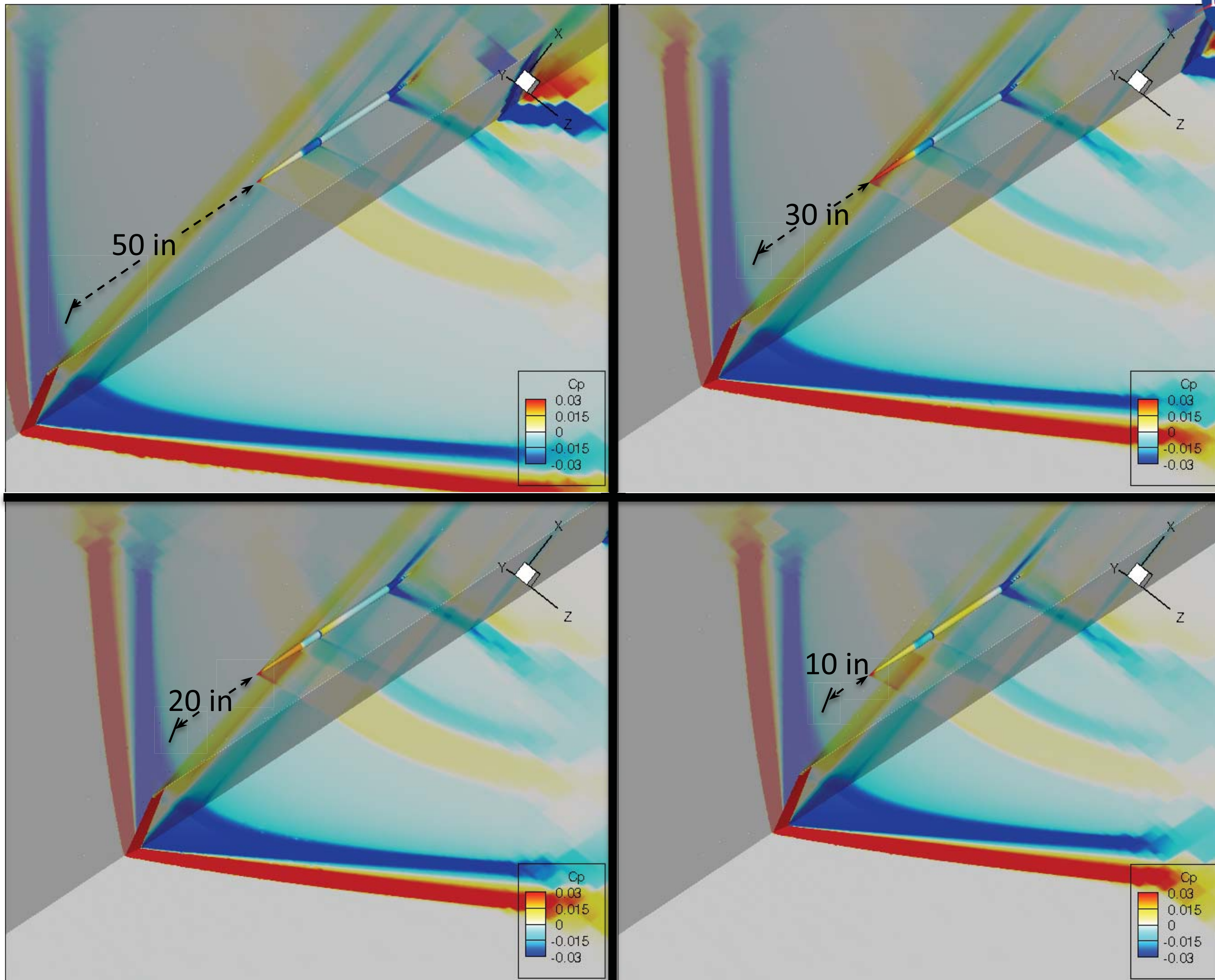
Good ● Fair ● Poor ●

RF 1.0 Rail Design Evaluated with CART3D



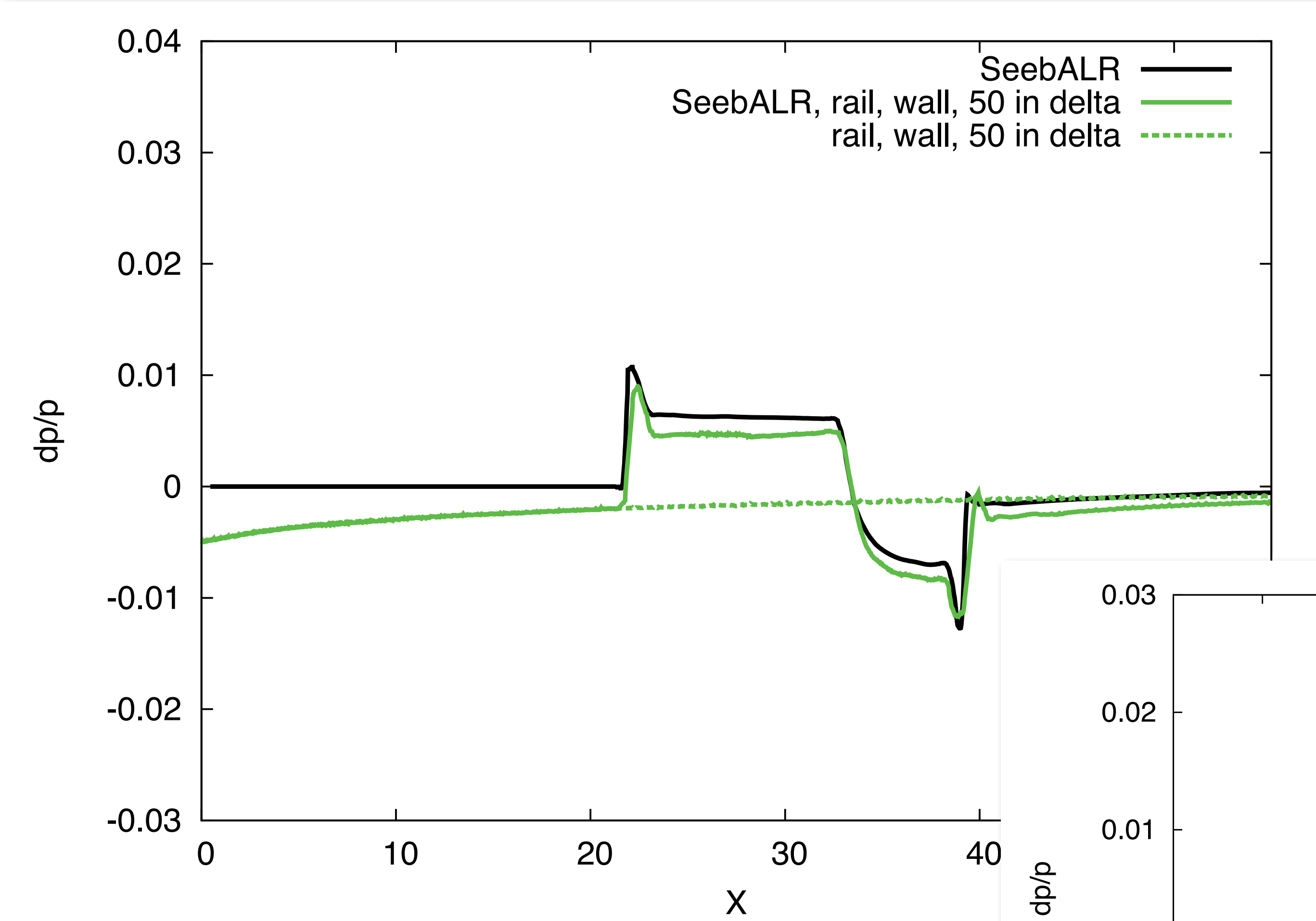


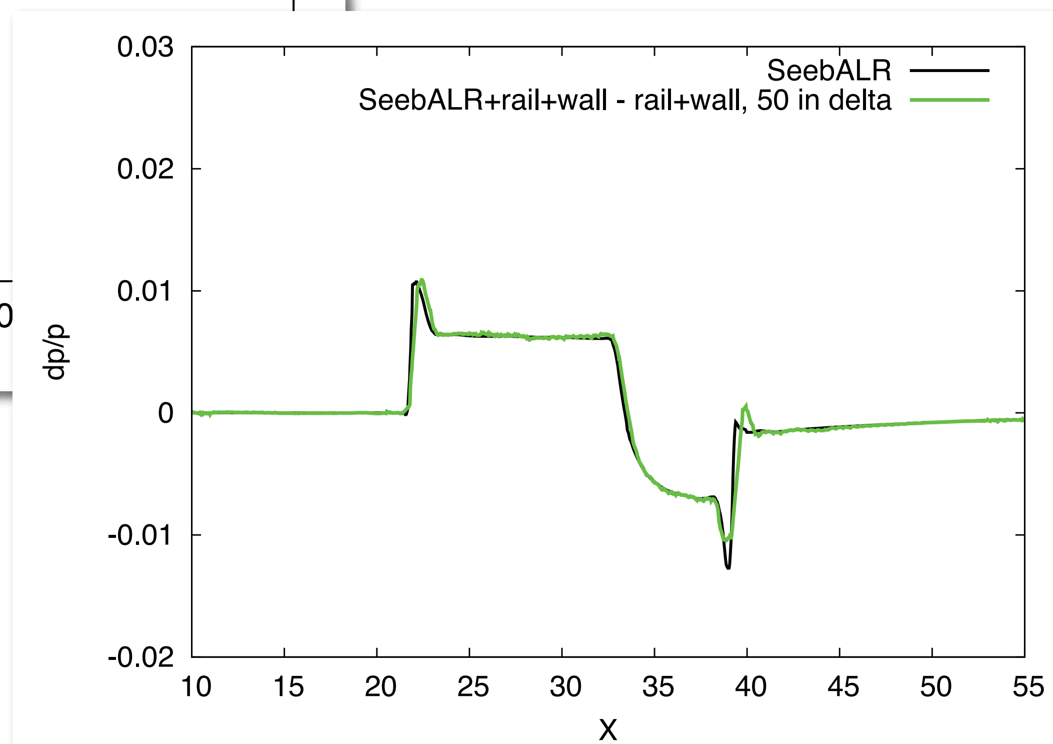
RF 1.0 Rail Evaluations, M= 1.6: CART3D



SeebALR Translating through RF 1.0 Rail Shock

M=1.6, H/L=1., Sensor 0.1 above tip





SeebALR Translating through RF 1.0 Rail Shock

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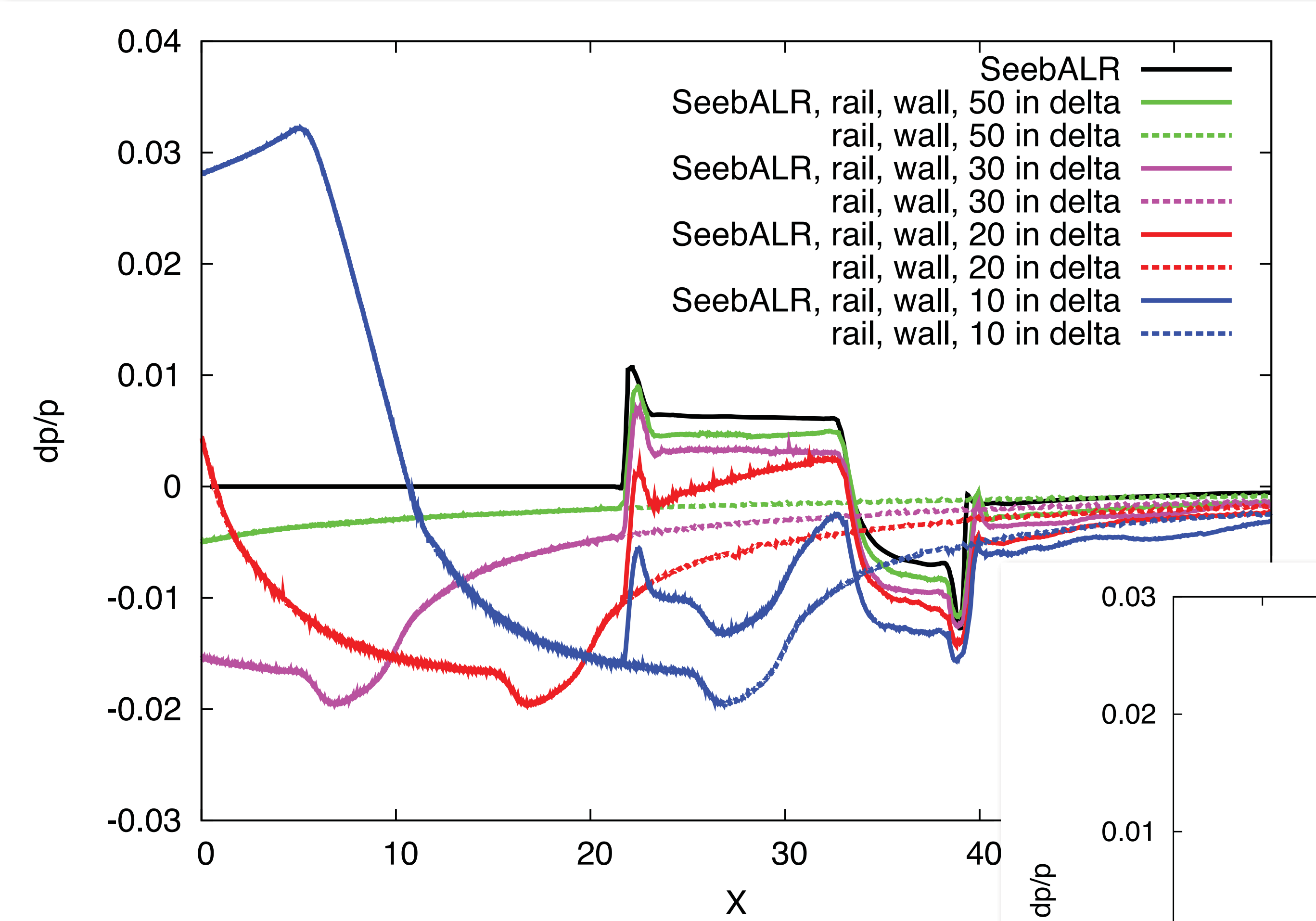
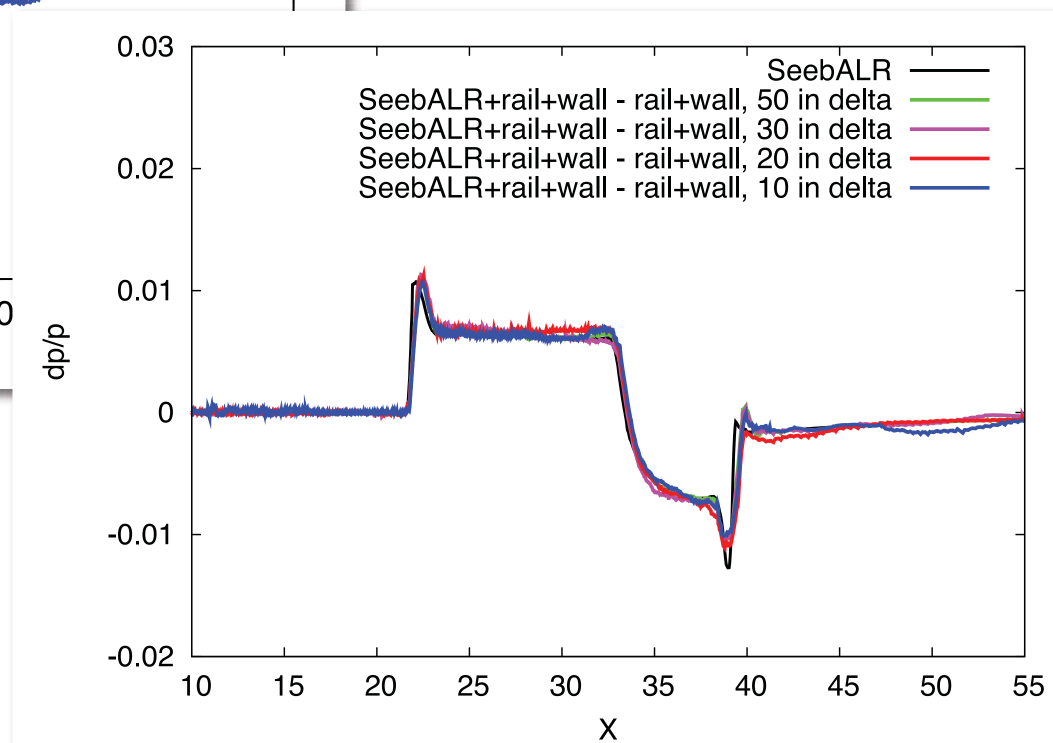


No effect from rail shock



Advantages of RF 1.0 rail

- Consistent reflection factor of 1.0 (no scaling required)
- Small circular radius tip permits 3D flow (equivalent diameter of conventional probe at orifice)
- Model shocks will reflect downstream of signatures and not corrupt signature
- Rail has weaker leading shock and little if any impact on accuracy if model is behind or translated through shock than conventional rails
- Outside boundary layer, no Mach differential between rail and model

Techniques for Improved Sonic Boom Data

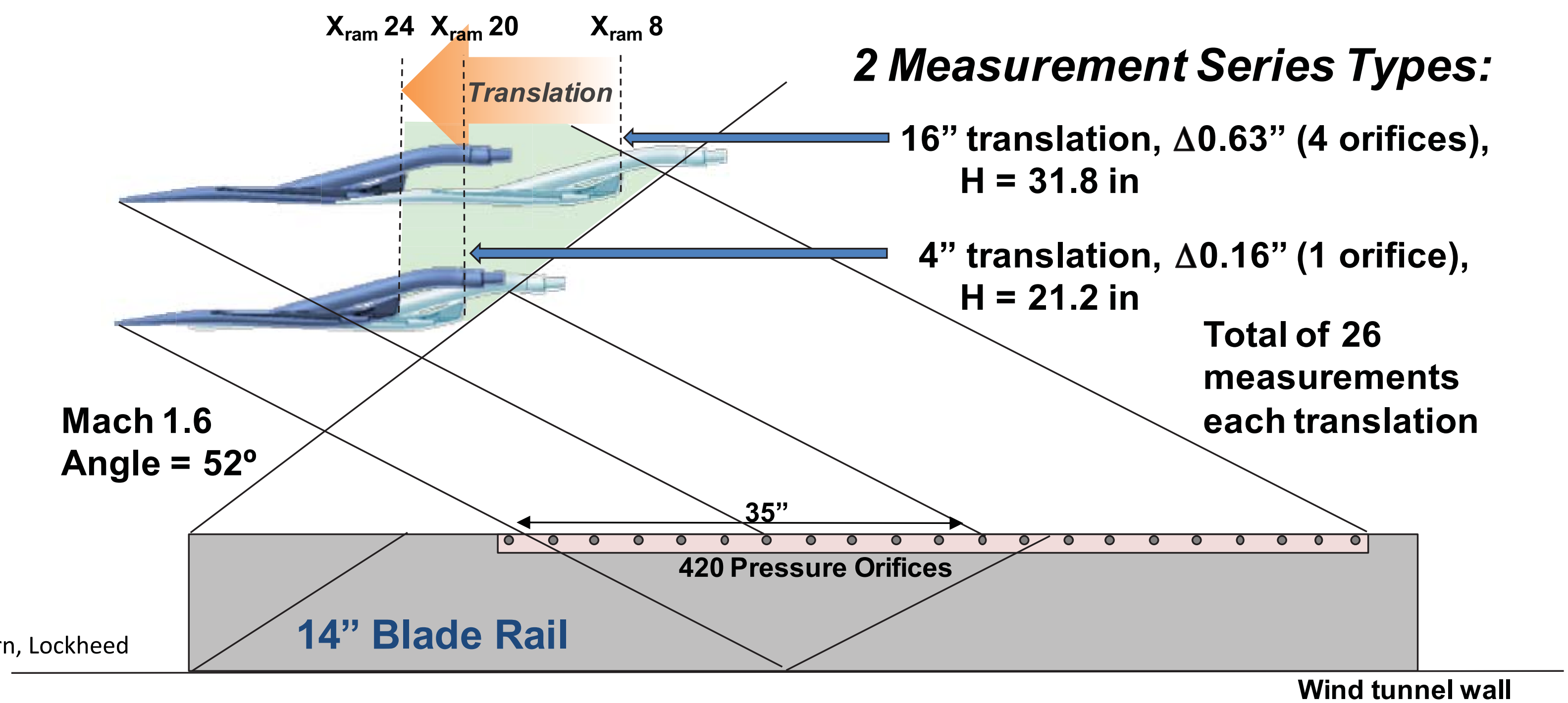
- Spatially average data at constant h/L (within either 4”or 16” total travel)
- Ptotal above atmospheric pressure (2300 psf) and constant (within 1 psf)
- Hold humidity constant (within ~4 ppm)
- Utilize RF 1.0 rail (model reflection downstream of signature)
- Rail in forward window blank
- Position model upstream of rail influence
- Increase signal to noise ratio
  - Larger model
  - Smaller h/l
- Increase duration of reference and data runs
  - Important for individual (non-averaged) runs

Spatial Averaging Technique

- Runs comprise a series of axial translations
  - 26 positions (longitudinal translations)
  - 4” or 16” traverse lengths (1- or 4- orifice spacing between positions)
- Align pressure signatures, shift by actuator position
- Average aligned pressure signatures, $\bar{f} = \frac{\sum f_i}{N}$, where N is number of positions
- Compute standard deviation of each point from averaged signature

$$\sigma = \sqrt{\frac{\sum (f_i - \bar{f})^2}{N}}$$

- Choose reference run with minimum average standard deviation over entire signature

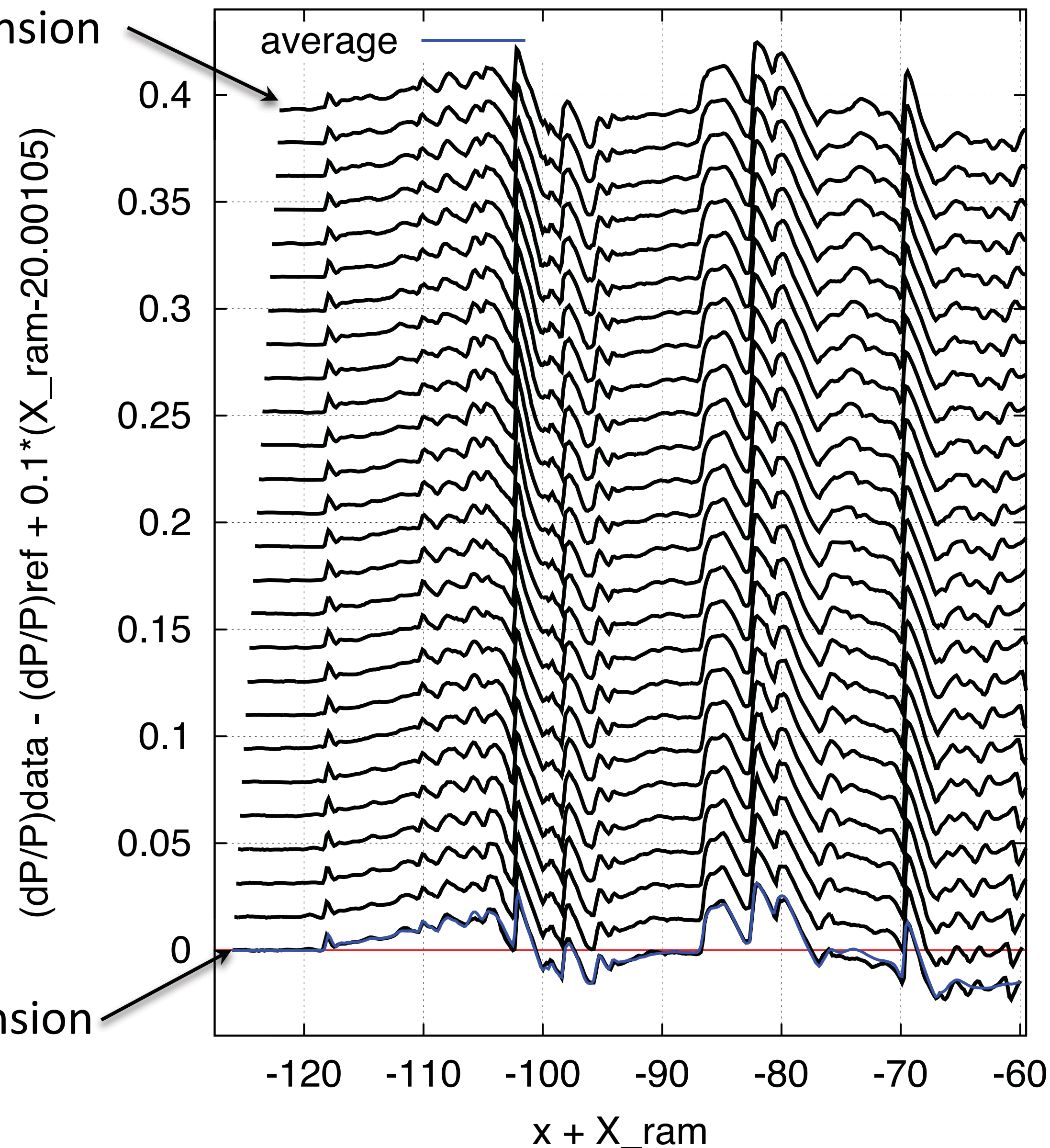


John Morgenstern, Lockheed

Align Signatures by "X_ram"

LM N+2 Blade Sting Model, M=1.6, H~ 20.7, α~ 2.3

Maximum Ram Extension
Run 799

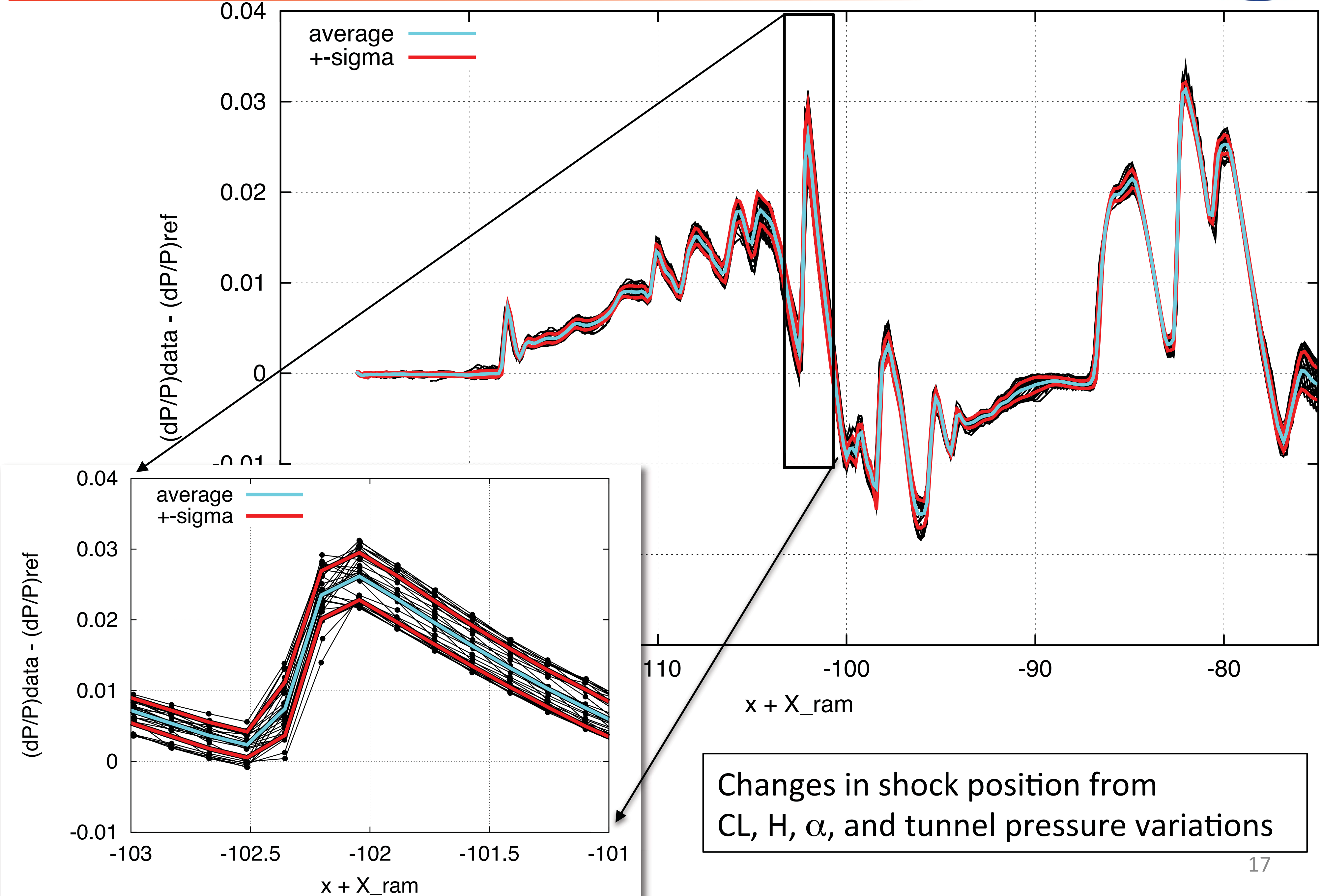


Minimum Ram Extension
Run774

Runs 774 to 799,
Ref 828

Shifted/Averaged LM3 Test Data using RF 1.0 Rail

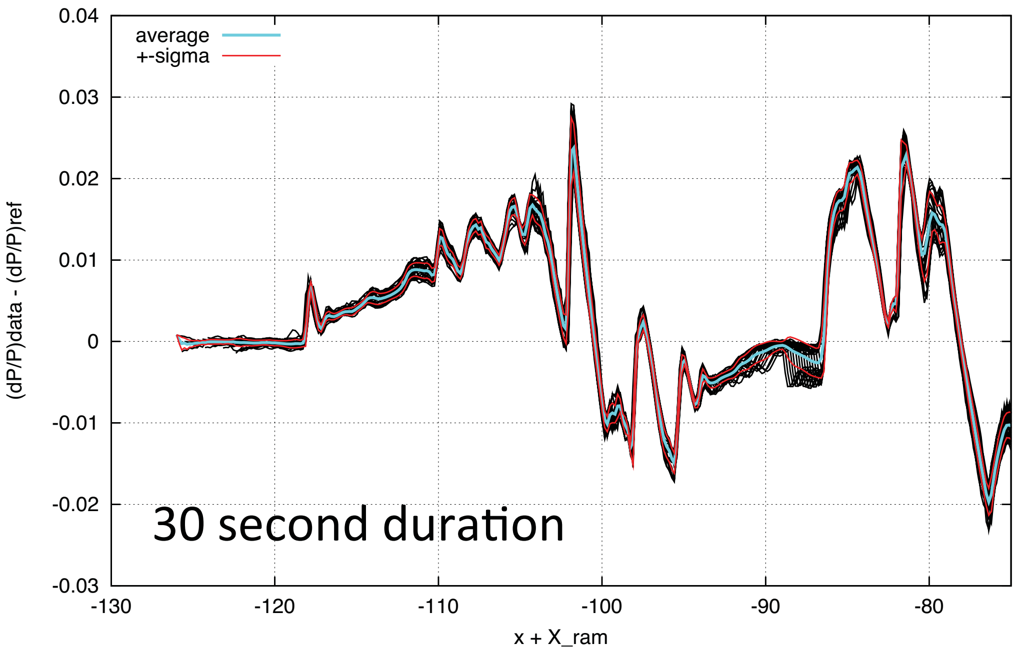
LM N+2 Blade Sting Model, M=1.6, H~ 20.7, α~2.3

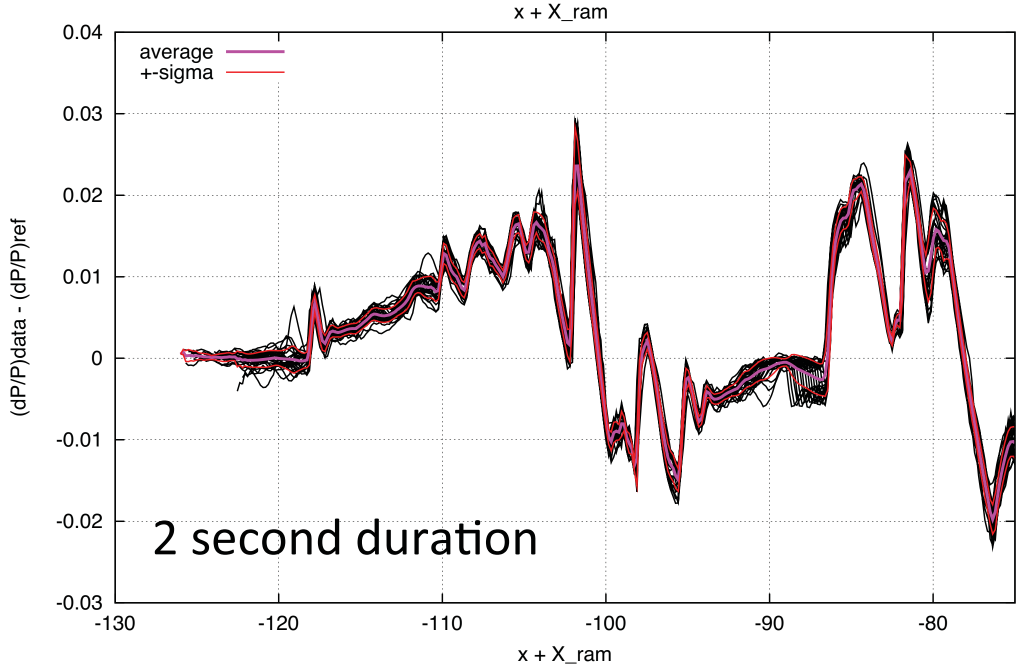


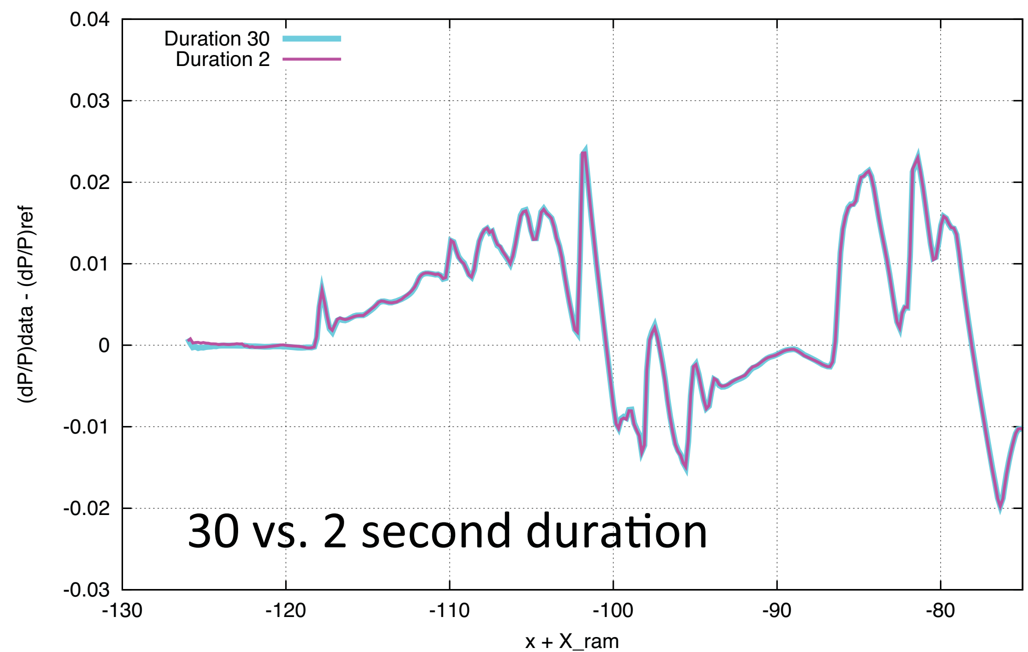
Changes in shock position from
CL, H, α, and tunnel pressure variations

Shifted/Averaged LM3 Test Data using RF=1 Rail

Duration Studies: N+2 Blade Sting







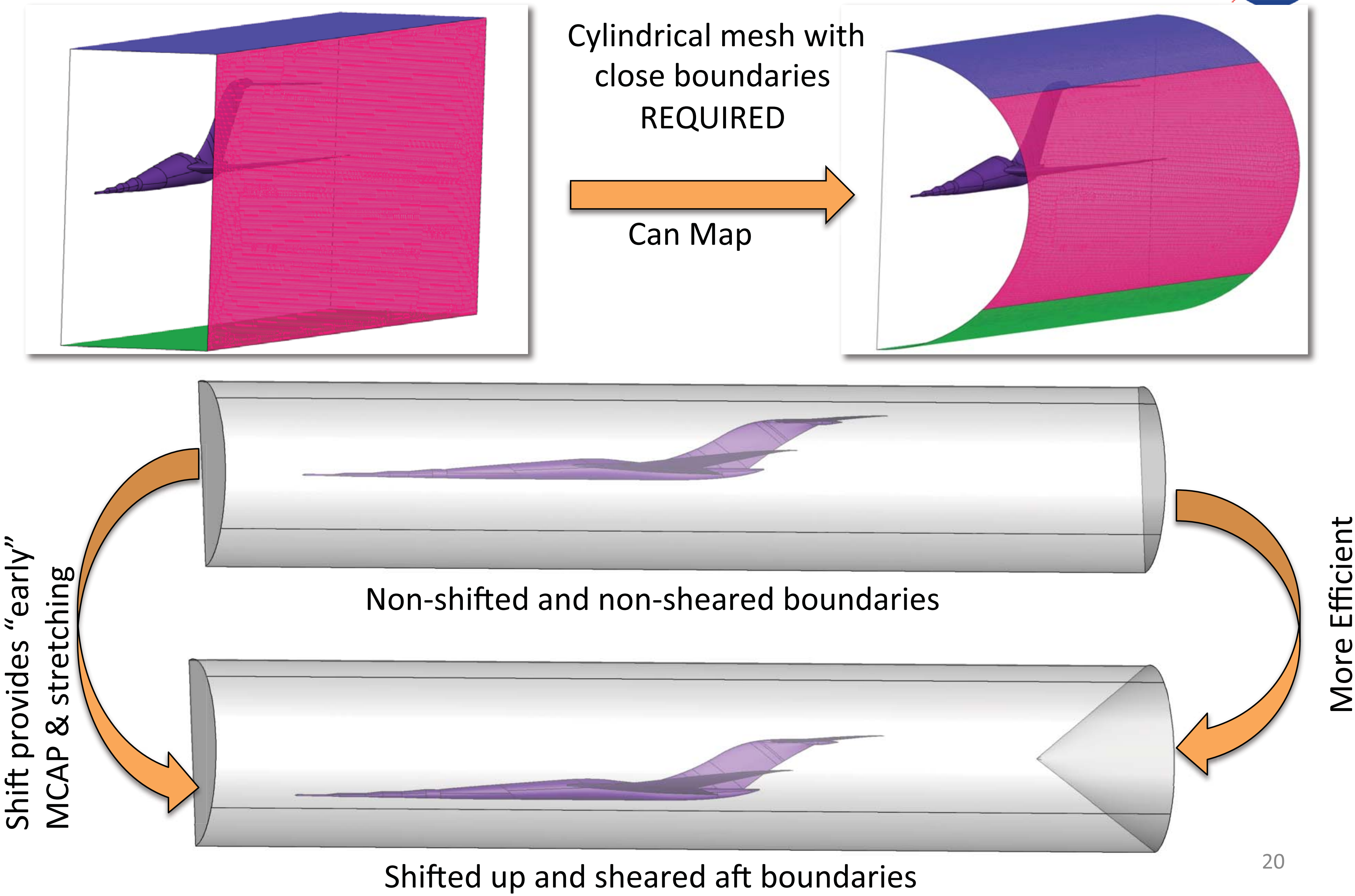
Runs 333 to 358, Ref 359

CFD Grid Generation for Boom Analysis with Unstructured Tetrahedra Codes

Mach Cone Aligned Prism (MCAP) Grid Development

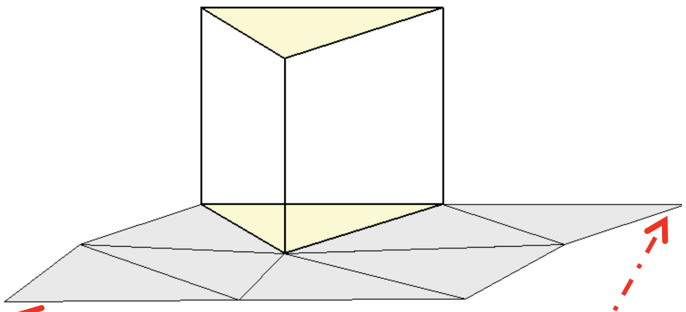
- Accurate sonic boom pressure signatures at several body lengths
- Single mesh for accurate boom and drag
- Robust stretching / shearing method for tetrahedral meshes
- Single mesh for on- and off-track pressure signatures
- Automated tool to construct mesh with hands-off control

Developing a Near-Field Cylindrically-Shaped Mesh

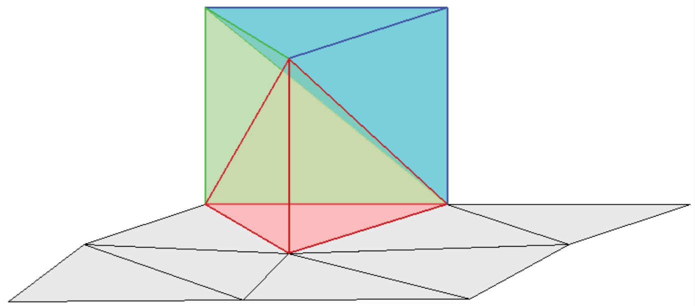


Projecting a Layered Cylindrically-Shaped Prism Mesh

Project face on cylinder outer boundary in radial direction

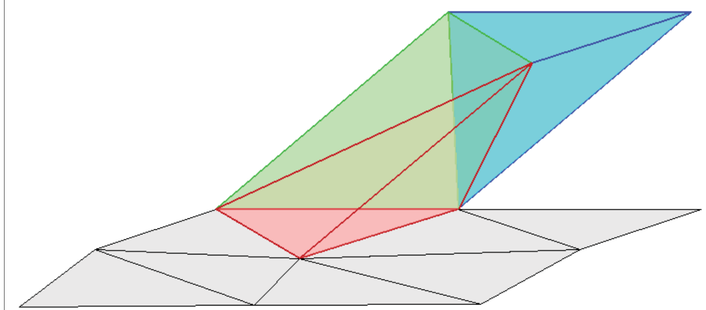


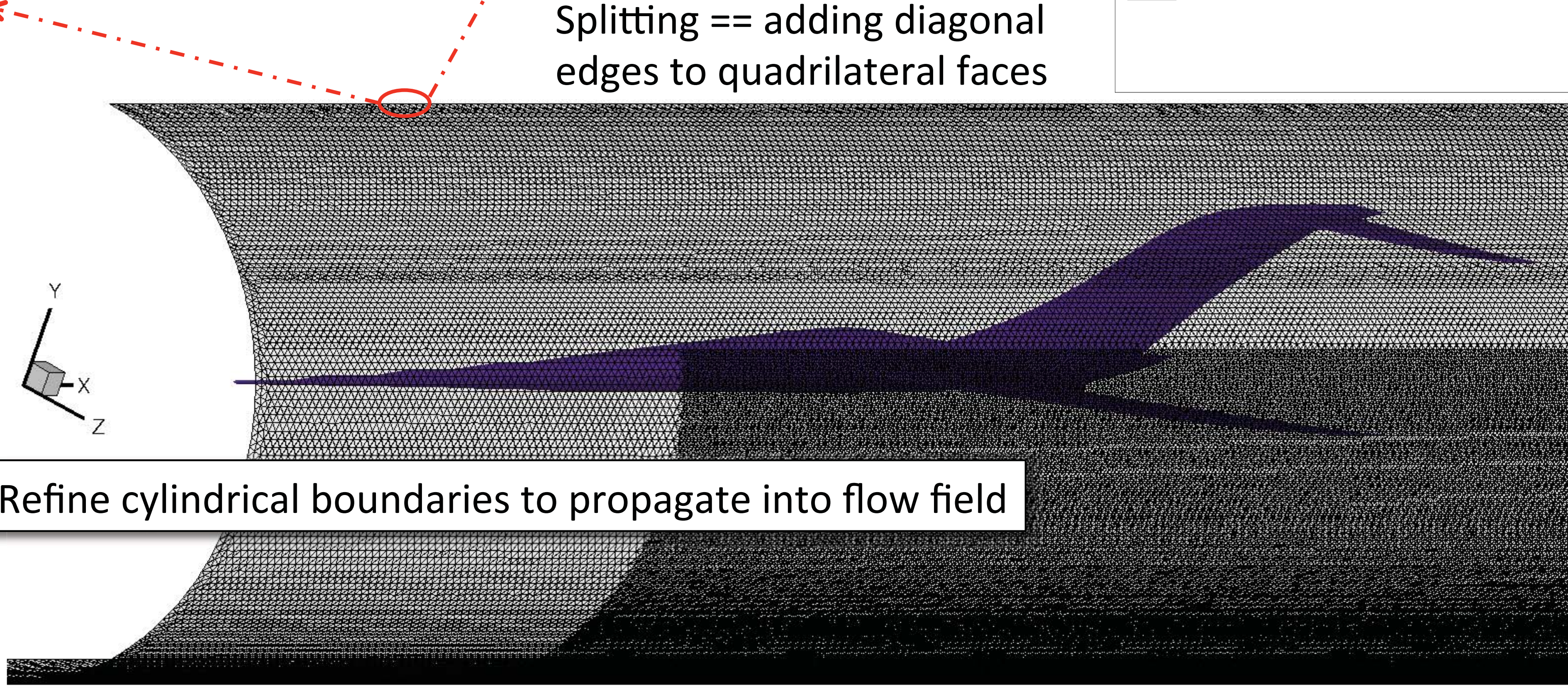
Split each prism into three tetrahedra



Splitting == adding diagonal edges to quadrilateral faces

Exploding tetrahedra of sheared prism

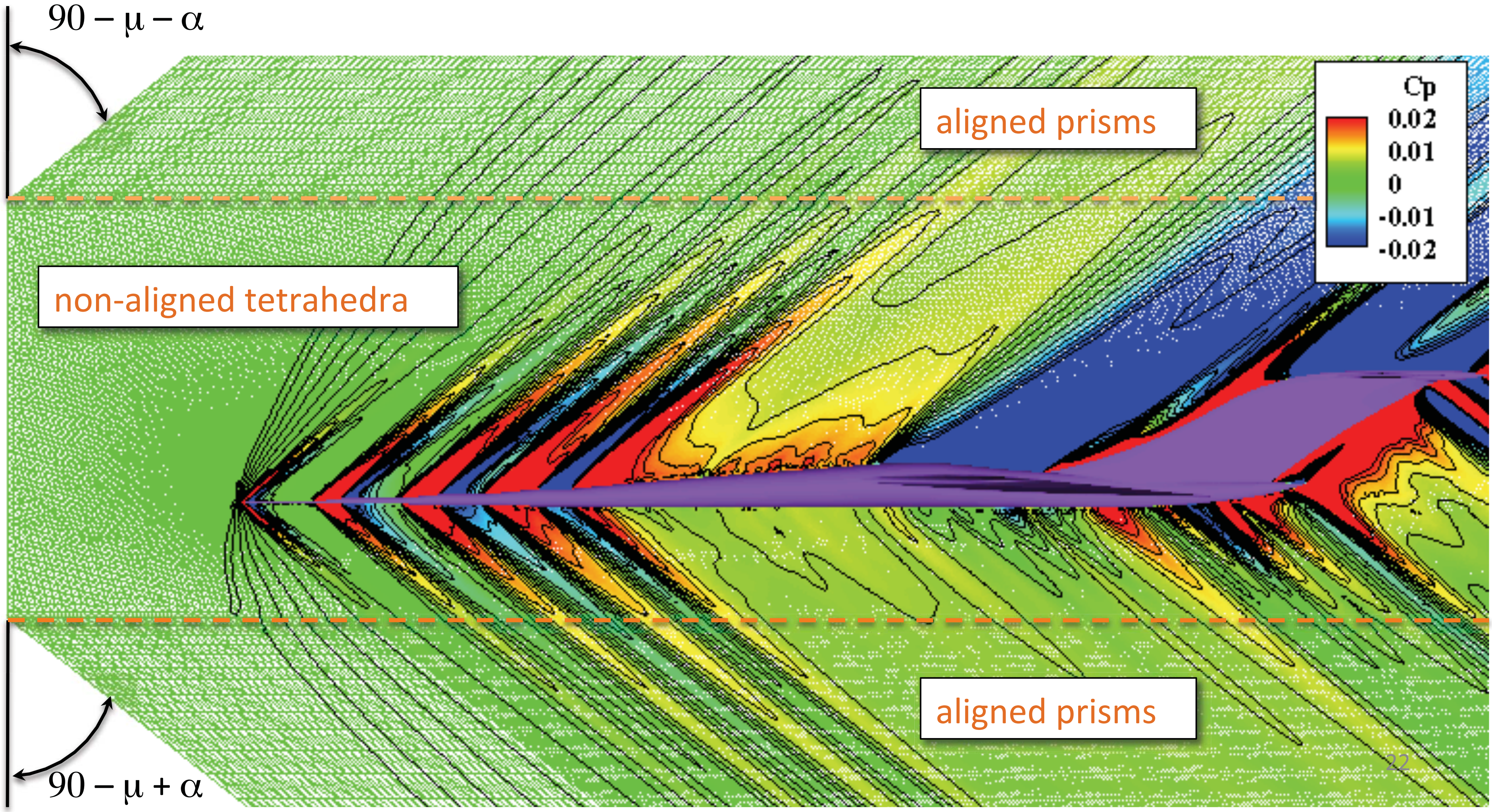




Refine cylindrical boundaries to propagate into flow field

Shearing/Mach Angle Alignment of Prismatic Grid

α= angle of attack
μ= $\sin^{-1}(1/M)$



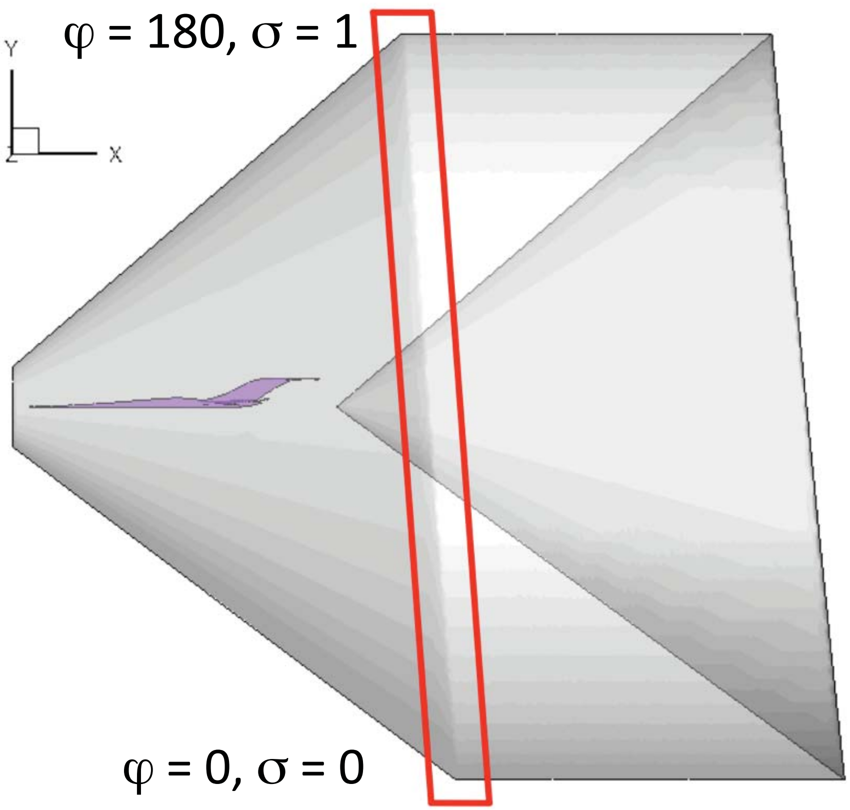
Alignment and Circumferential Refinement of Outer Prismatic Grid

α aligned with cosine function to transition from under-track to above model;
Weighting function $\sigma = (1 - \cos(\varphi))/2$

dX added to X of each point where

$$dX = dR / \tan(\nu) \text{ where}$$

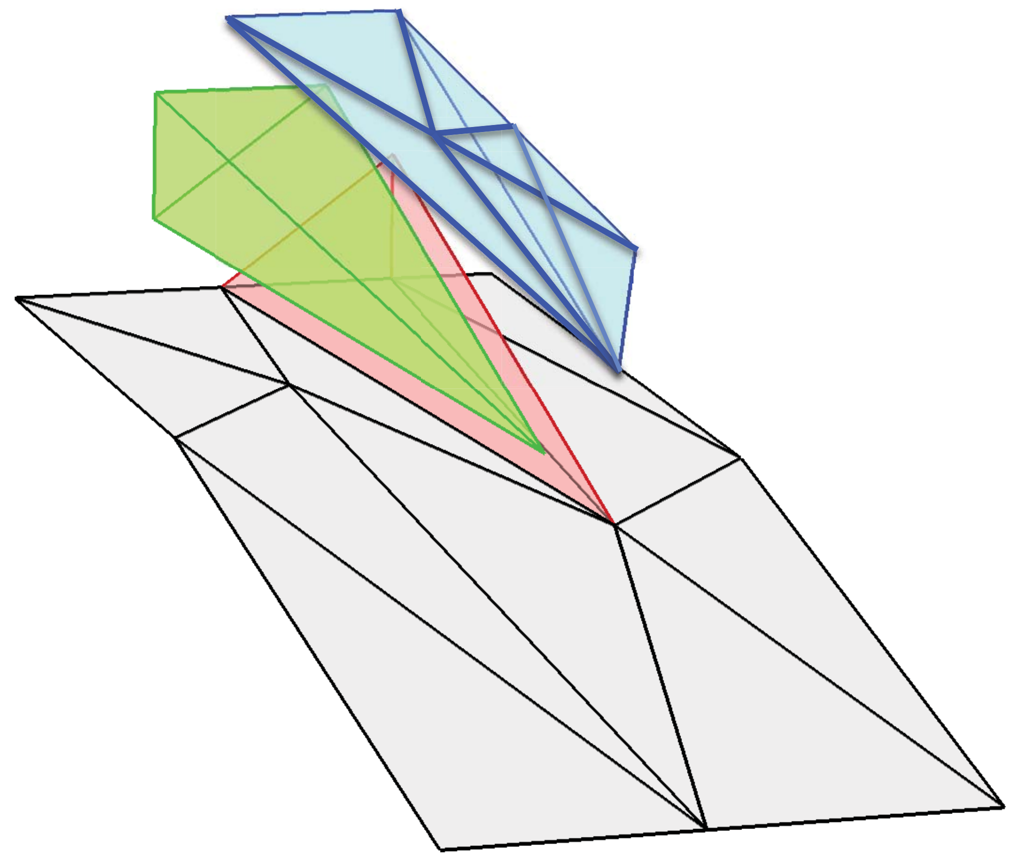
$$\nu = \mu + ((-\alpha)(1 - \sigma) + (\alpha)\,\sigma)$$



Longest 2 edges of face split

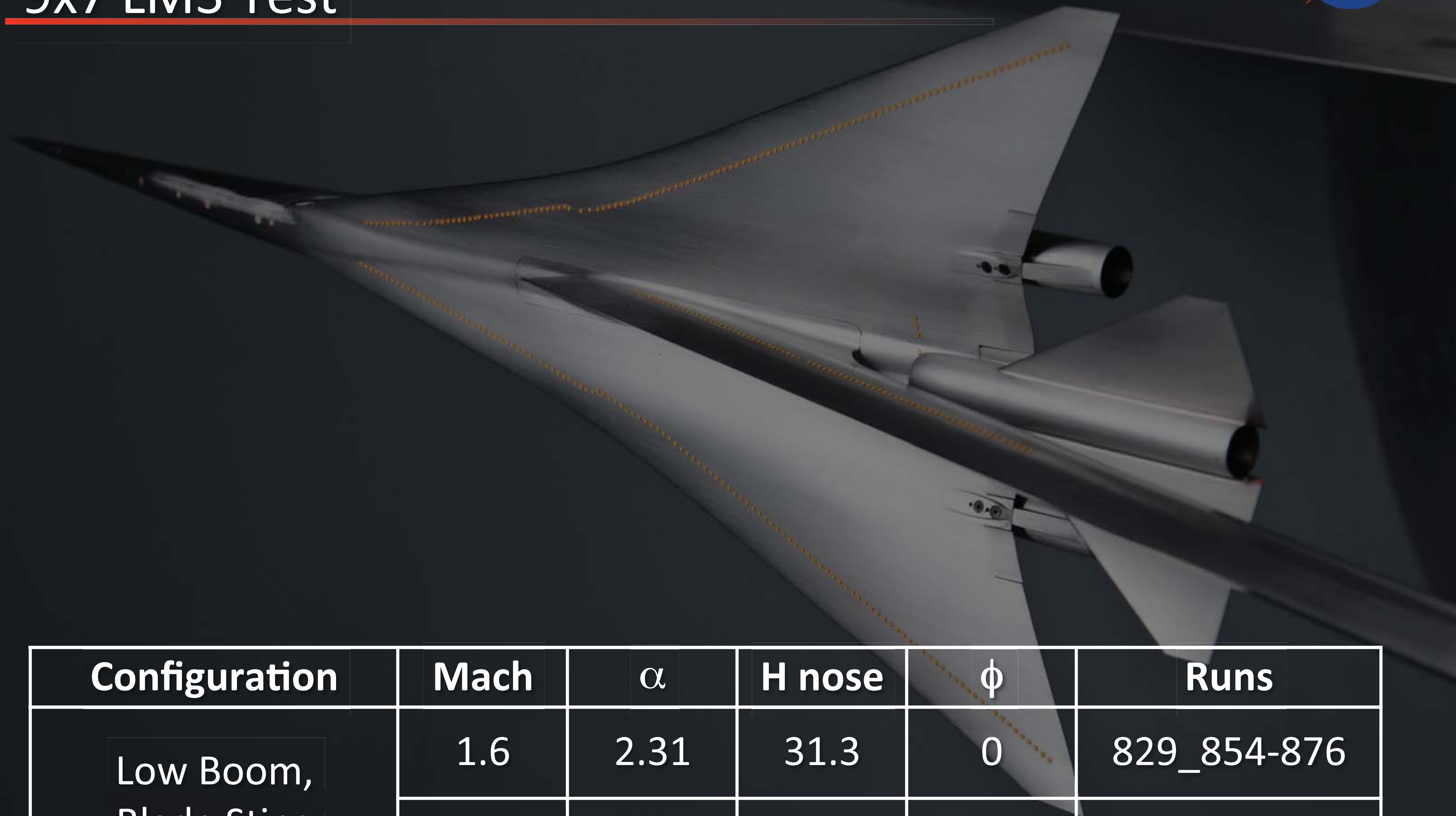
Split tetrahedron of split face

Copy connectivity to subsequent layers



Computational-Experimental Results

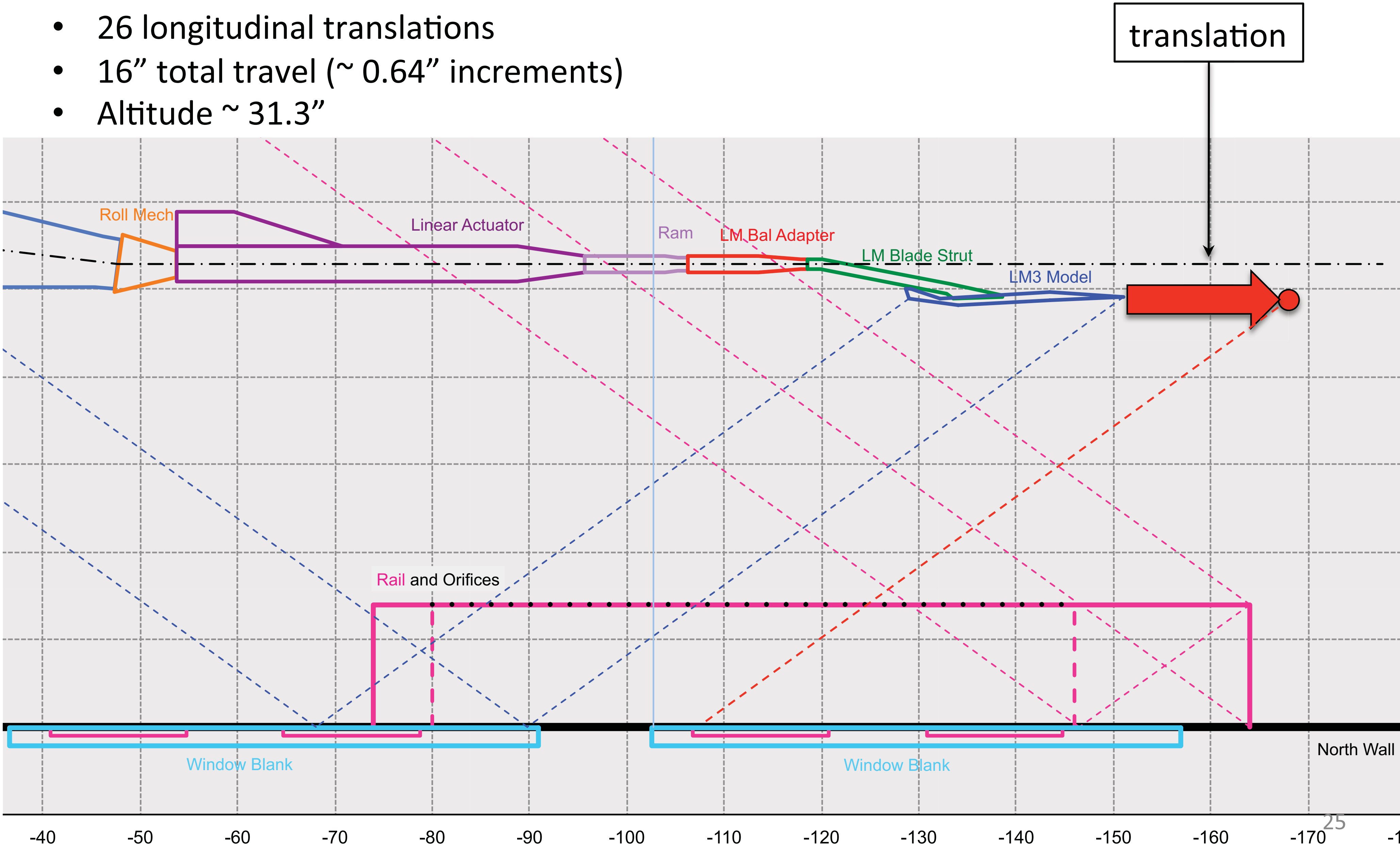
9x7 LM3 Test



Configuration	Mach	α	H nose	ϕ	Runs
Low Boom, Blade Sting	1.6	2.31	31.3	0	829_854-876
	1.6	2.5	31.4	0	855_874-876

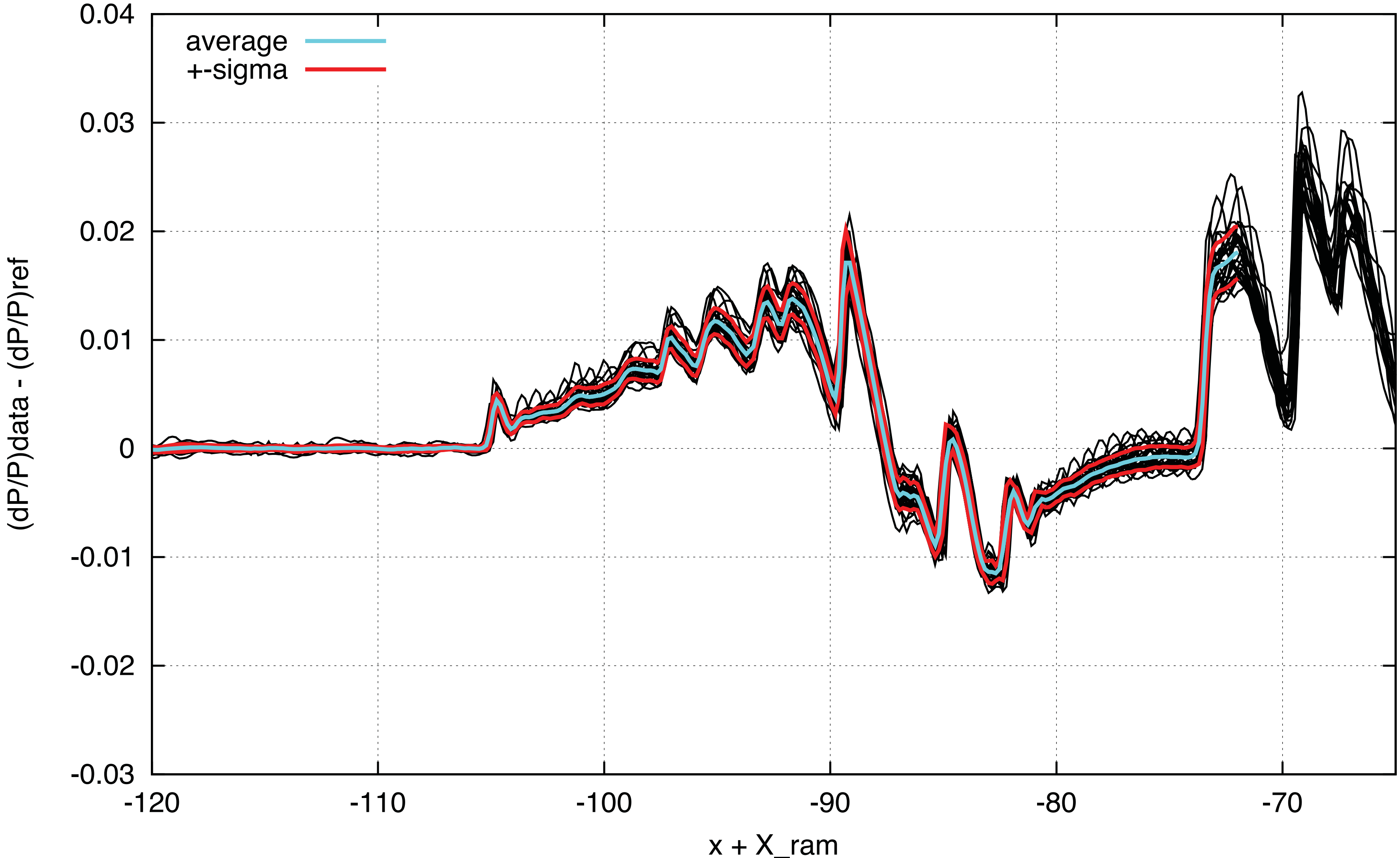
Tunnel Layout: LM N+2 Blade Sting

- Mach 1.6
- 26 longitudinal translations
- 16” total travel (~ 0.64” increments)
- Altitude ~ 31.3”



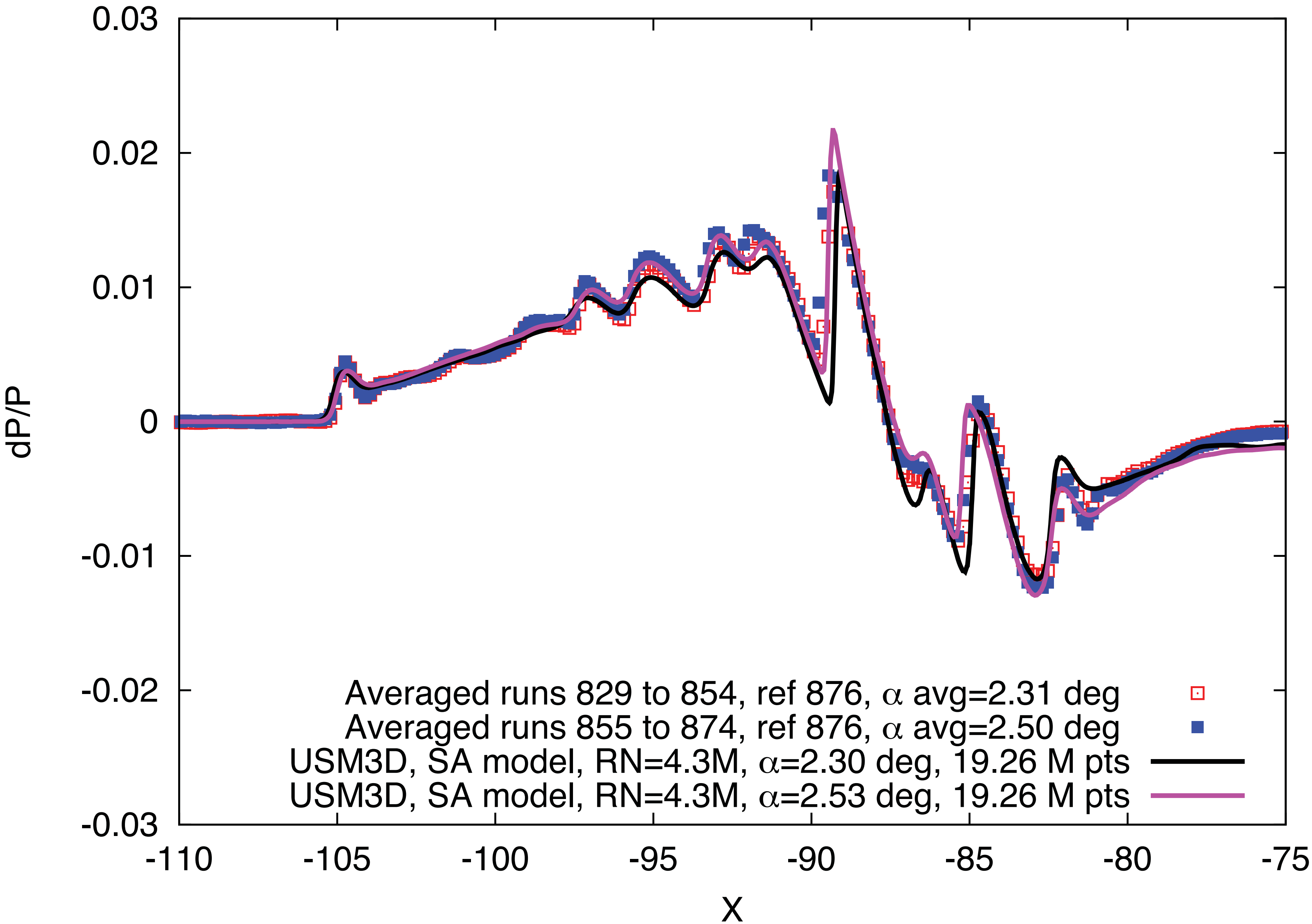
Shifted/Averaged LM3 Test Data using RF 1.0 Rail

LM N+2 Blade Sting Model, M=1.6, H~ 31.3, α~2.3



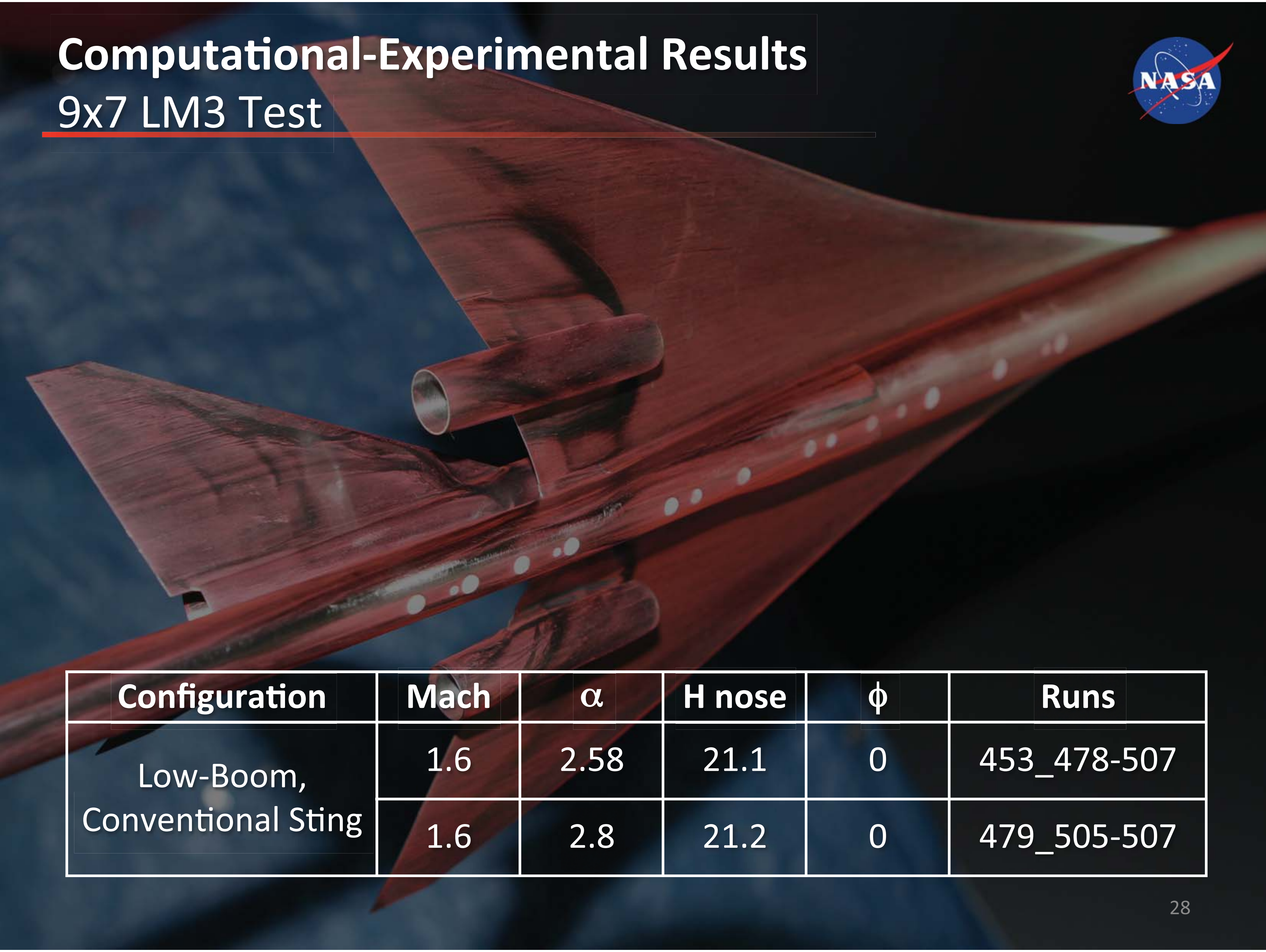
CFD vs. Shifted/Averaged LM3 Test Data

LM N+2 Blade Sting Model, M=1.6, H [31.32:31.38], α [2.21:2.53]



Computational-Experimental Results

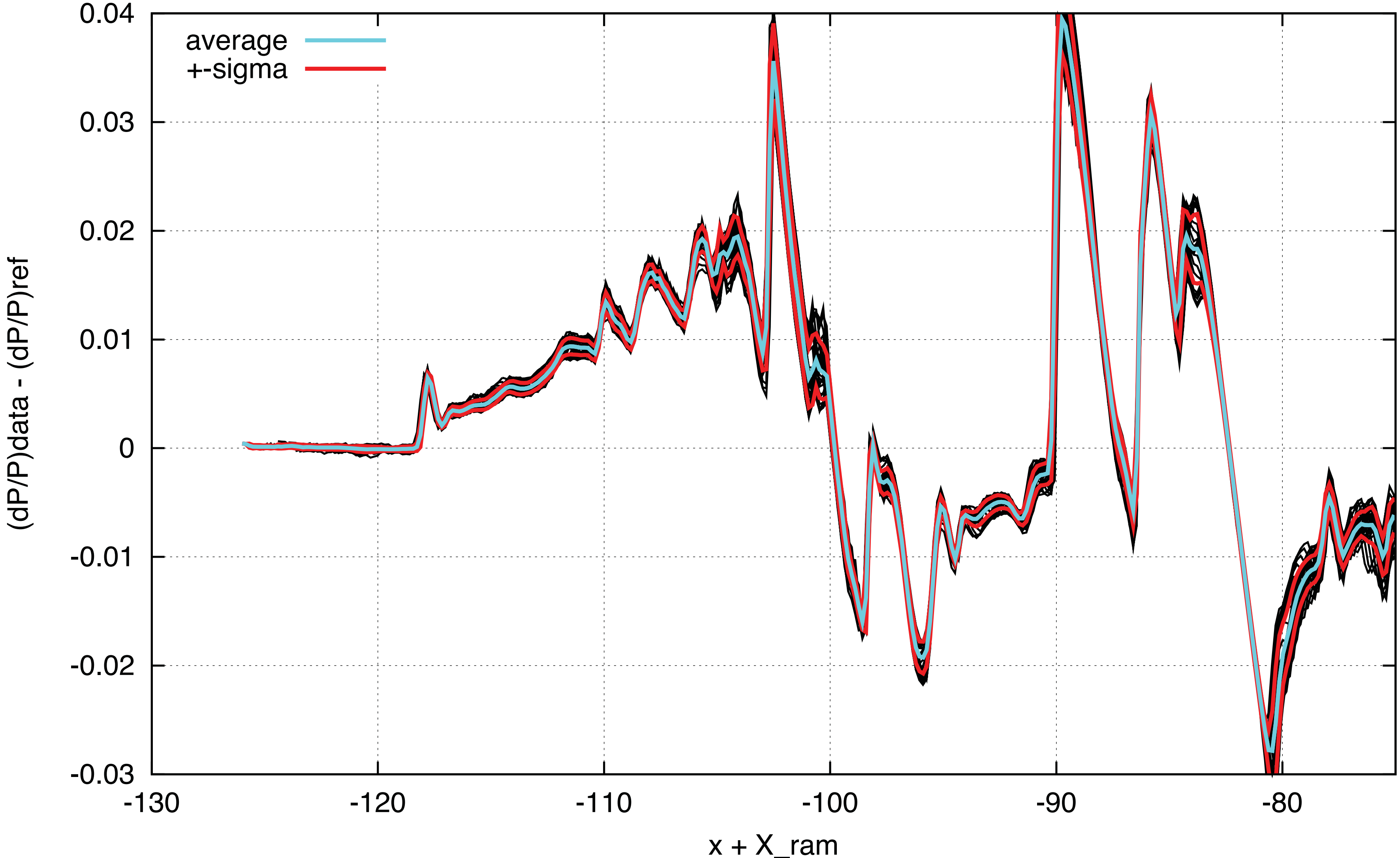
9x7 LM3 Test



Configuration	Mach	α	H nose	ϕ	Runs
Low-Boom, Conventional Sting	1.6	2.58	21.1	0	453_478-507
	1.6	2.8	21.2	0	479_505-507

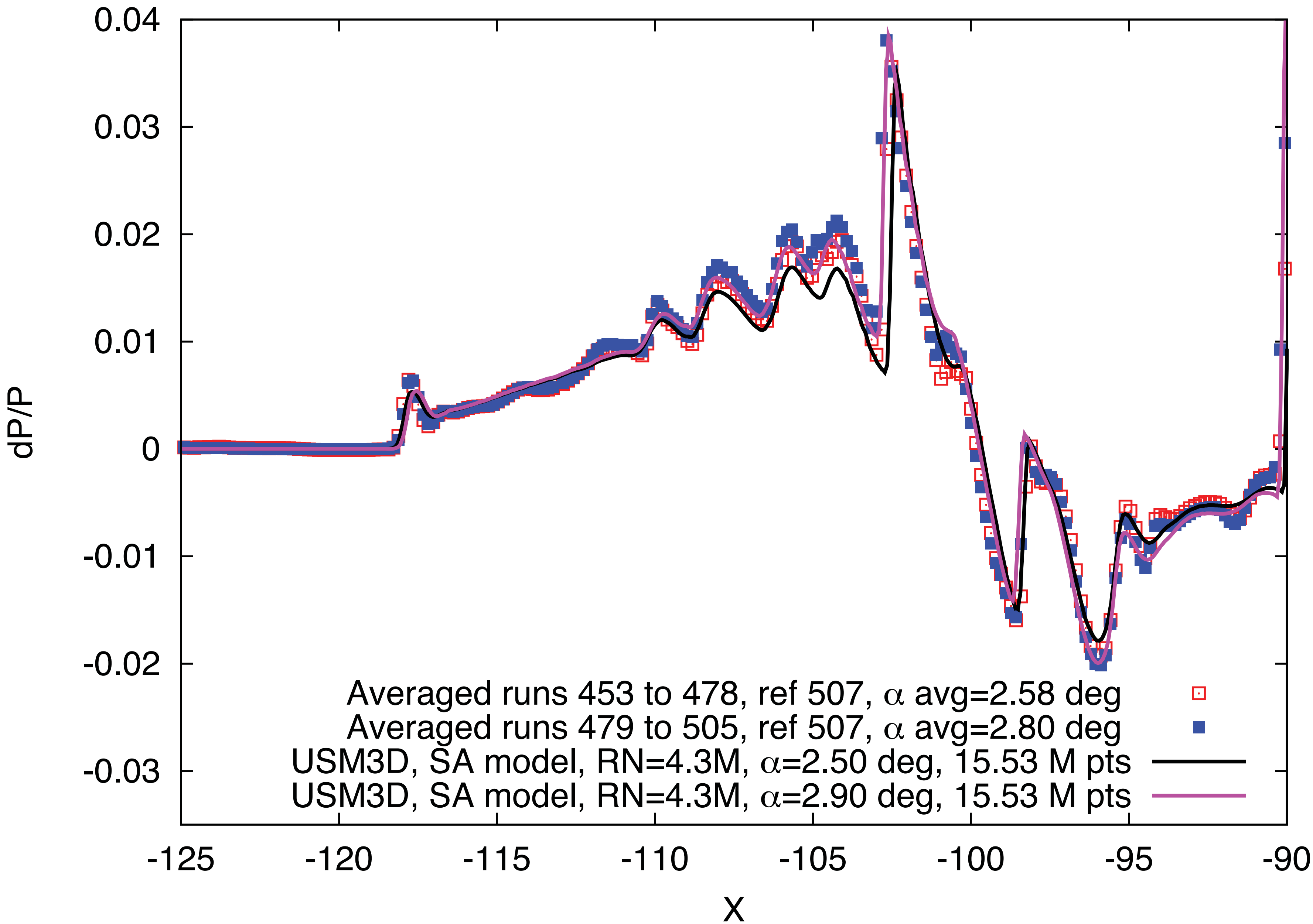
Shifted/Averaged LM3 Test Data

LM N+2 Conventional Sting Model, M=1.6, H~ 21.1, α~ 2.6



CFD vs. Shifted/Averaged LM3 Test Data

LM N+2 Conventional Sting Model, M=1.6, H [21.06:21.26], α [2.50:2.93]



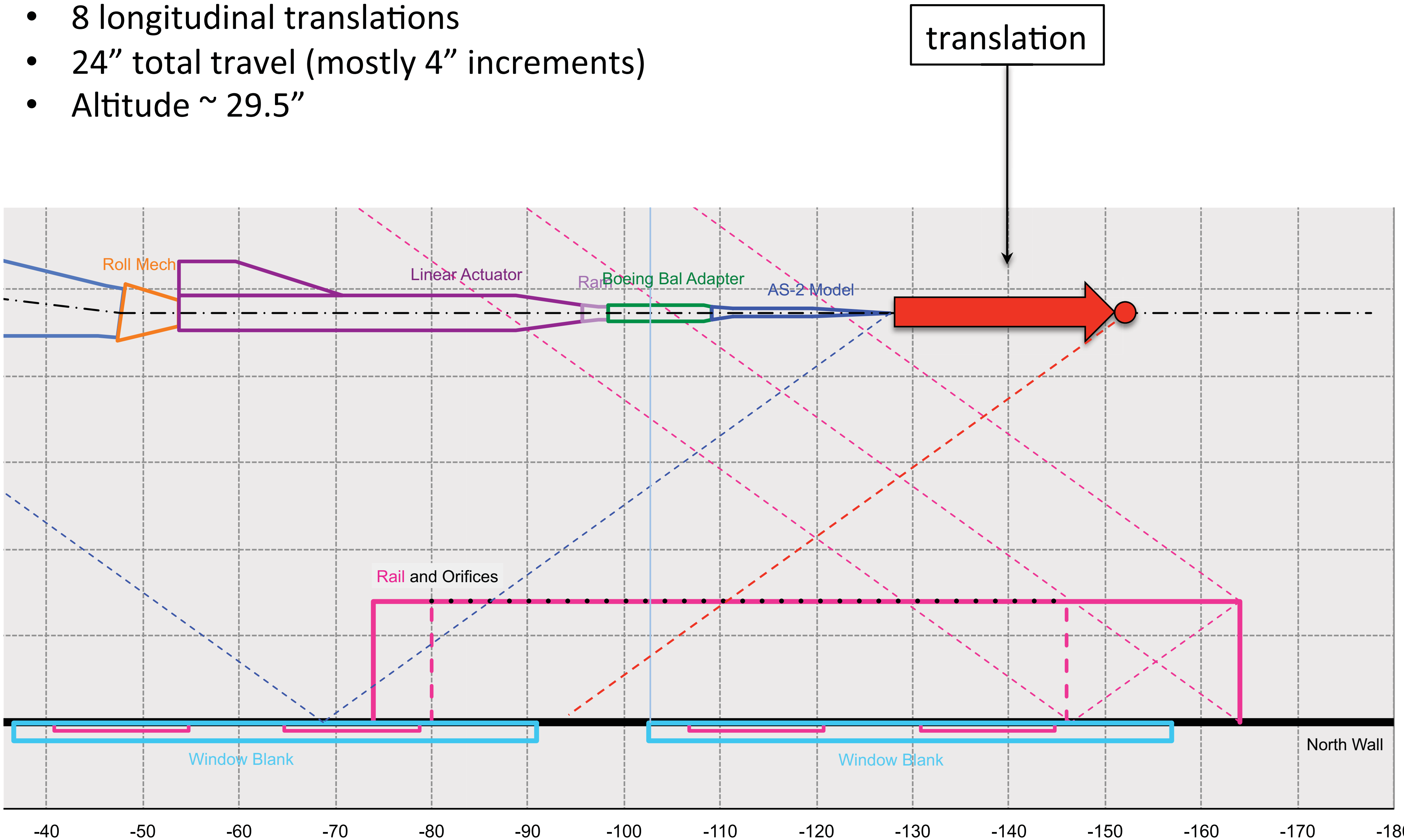
Computational-Experimental Results

9x7 LM3 Test

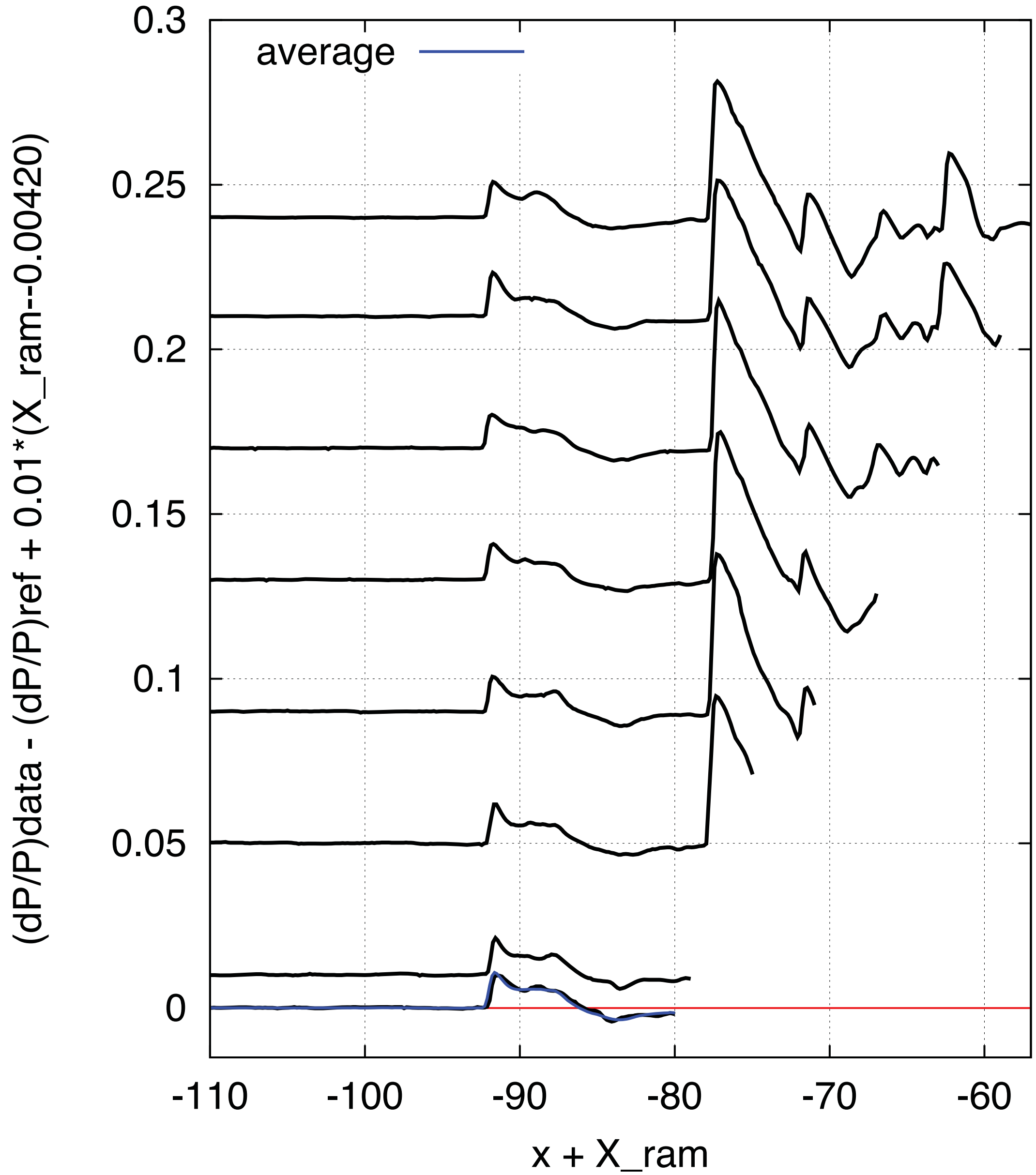
Configuration	Mach	α	H nose	ϕ	Runs
AS2	1.6	-0.27	29.5	0	918_925-927

Tunnel Layout: AS2 Model

- Mach 1.6
- 8 longitudinal translations
- 24" total travel (mostly 4" increments)
- Altitude ~ 29.5"

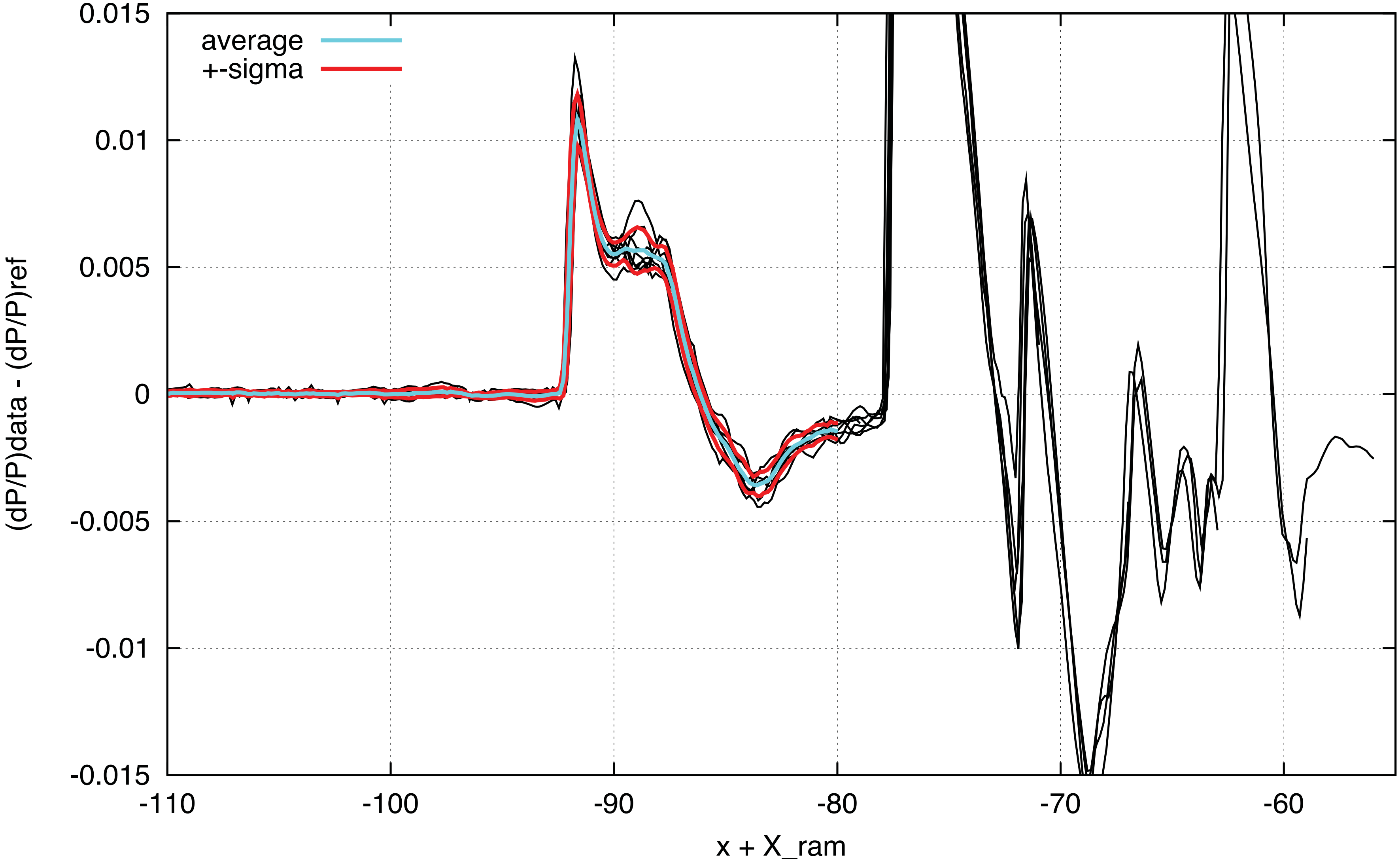


LM3 Test Data, AS2
M=1.6, H~ 29.5, α =-0.27, RN=2.88 M



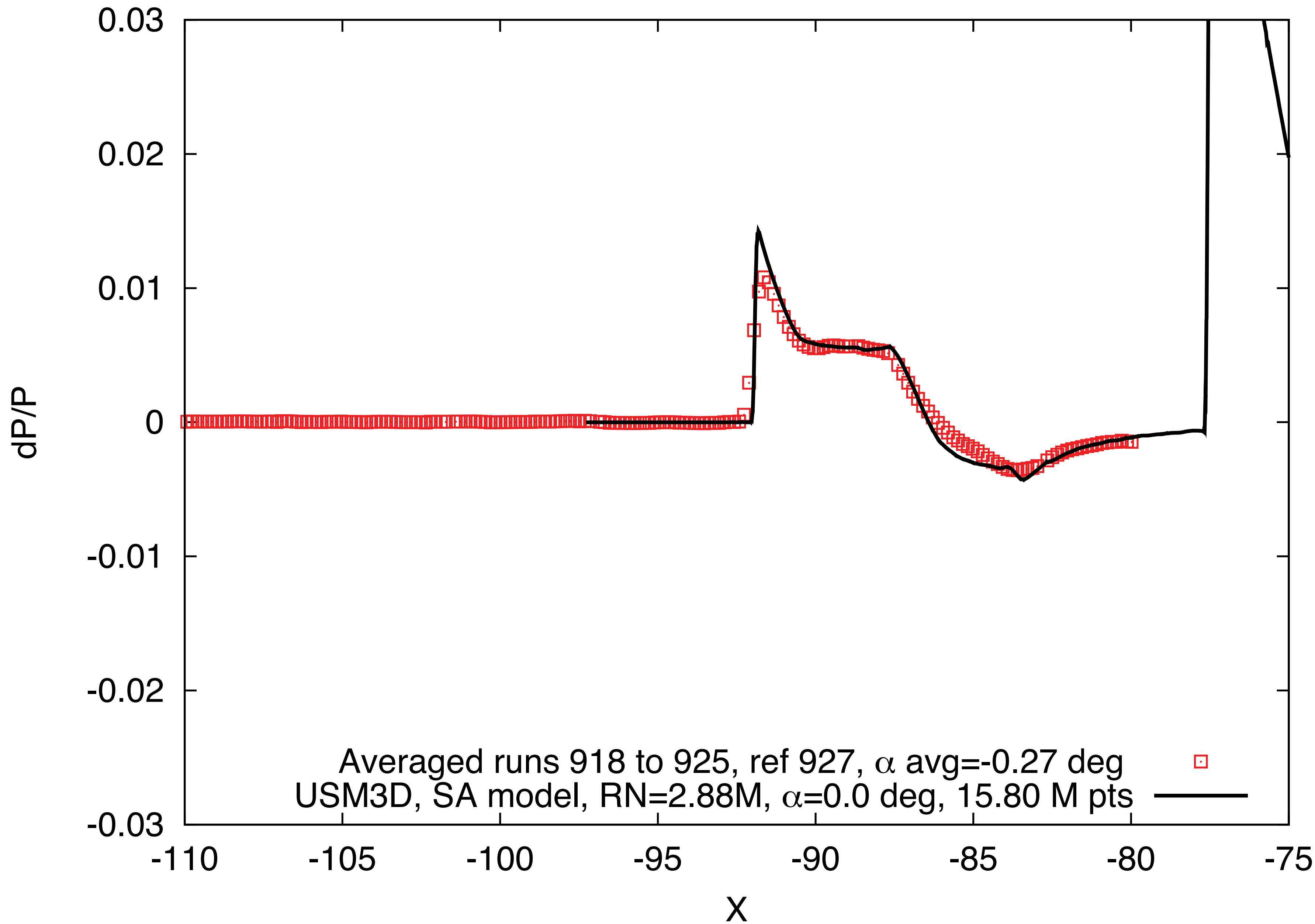
Shifted/Averaged LM3 Test Data

Boeing AS2 Model, M=1.6, H~ 29.5, RN =2.88 M



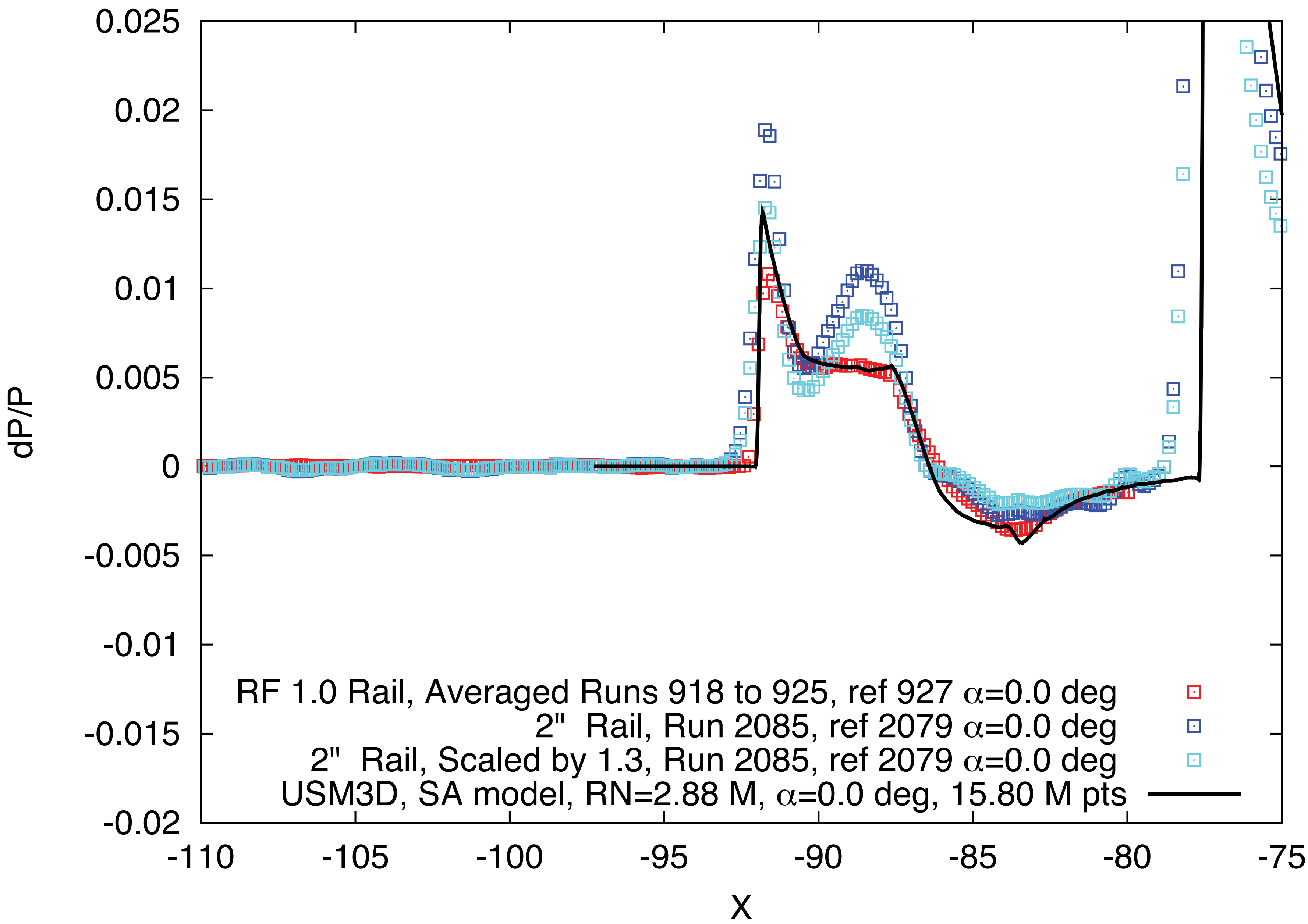
CFD vs. Shifted/Averaged LM3 Test Data

AS2 Model, M=1.6, H~29.5, RN=2.88 M, H [29.47:29.56], α [-0.28:-0.26]



Conventional Rail Data vs. RF 1.0 Rail Data vs. CFD

AS2 Configuration, M=1.6, H~30”



NASA-Led 9x7 Parametric Test

- Goals
  - Determine best facility operational modes balancing data quality and productivity
    - Humidity, P total
  - Determine best combination of sonic boom test hardware and technique to be used in future sonic boom testing
    - RF 1.0 and conventional rails, spatial averaging technique
- Particulars
  - NASA personnel are principal investigators
  - April 2 (1 week, 2 shift operation)
  - Lockheed and Boeing N+2 low boom wind tunnel models